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B. T. GALLOWAY, *Chief of Bureau.*

DIMORPHIC BRANCHES IN TROPICAL CROP PLANTS:

COTTON, COFFEE, CACAO, THE CENTRAL AMERICAN RUBBER TREE, AND THE BANANA.

BY

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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Plant Industry,
Office of the Chief,
Washington, D. C., August 2, 1910.

Sir: I have the honor to transmit herewith a paper entitled "Dimorphic Branches in Tropical Crop Plants: Cotton, Coffee, Cacao, the Central American Rubber Tree, and the Banana," by Mr. O. F. Cook, Bionomist of this Bureau, and to recommend its publication as Bulletin No. 198 of the Bureau series. The paper shows that each plant produces two different kinds of branches, and points out numerous agricultural applications of these specialized habits of growth.

Respectfully,

G. H. Powell,
Acting Chief of Bureau.

Hon. James Wilson,
Secretary of Agriculture.

CONTENTS.

198

ILLUSTRATIONS.

PLATES.

TEXT FIGURES.

198

B. P. I.—608.

DIMORPHIC BRANCHES IN TROPICAL CROP PLANTS: COTTON, COFFEE, CACAO, THE CENTRAL AMERICAN RUBBER TREE, AND THE BANANA.

INTRODUCTION.

It has been known for a long time that some species of plants have two or more forms of branches, but such specializations have been looked upon as botanical curiosities rather than as having practical significance in agriculture. Several of the most important economic species of the Tropics have now been found to have two or more different and distinct kinds of branches regularly present on every normal plant. These differences in the formation of the branches are worthy of scientific study and have definite relations to agricultural problems.

The specializations of the branches of the tropical crop plants are not mere inequalities of position and development like those that commonly appear among the trees and shrubs of the temperate regions. The differences do not arise merely from favorable or unfavorable positions on the plant that might affect the supply of food or the exposure to sunlight. The two kinds of branches are in most cases so definitely different that they do not replace or serve as substitutes for each other. The differences of the branches have sometimes been recognized by individual planters of coffee or cacao, but they have not received the study that the facts would warrant, either in their scientific aspects or in relation to practical agricultural applications.

As the best means of describing the nature and extent of the diversity of branches which exists in several of the more important tropical crop plants, it seems desirable to bring together in one report the facts of this kind which have been observed. The cultural significance of some of them is at once obvious and will show the desirability of further study in this class of phenomena. That much more information of this kind remains to be discovered seems strongly to be indicated by the fact that a definite diversity of branches has been found in all of the principal tropical crop plants to which attention has been directed with this idea in mind.

STRUCTURAL SIGNIFICANCE OF DIMORPHIC BRANCHES.

In attempting to understand the dimorphism of branches it is desirable to consider the nature of the structural units that compose the bodies of the plants. For some of the purposes of scientific study the individual cells or the tissues formed by the cells of one kind can be considered as units of structure. But many forms of plant and animal life also show structural units of a higher degree, such as the many similar joints or segments that compose the bodies of the worms and centipedes and the internodes of higher plants. Each joint is highly complex in itself, with a complete system of tissues and organs. The word " metamer " is used as a general term to apply to these complex units of organic structure. In some of the lower forms of animal life each metamer is capable of an independent existence, just as in some plants each joint of the stem or the rootstock, if planted as a cutting, will grow into a new individual. In a similar way each seedling represents a single metamer, able to produce others.

Two general groups of metamers may be recognized in plants—those that build up the vegetative parts of the plant and those that take part in the formation of the flowers and fruit. A vegetative metamer consists of a joint or section of the stem, together with a root or roots, and one or more leaves, as well as the hairs, scales, and other smaller appendages that belong to the joint, the root, or the leaf.

The floral or reproductive metamers of plants are generally smaller than the vegetative metamers. The part that corresponds to the joint or section of the stem of a vegetative internode is extremely short, while the part that corresponds to the leaf takes the form of a sepal, stamen, or pistil.

A plant as a whole represents a collective individual—a social organization, as it were—of the different kinds of subordinate metameric individuals, some devoted to vegetative purposes and some to reproduction. Botanical writers have often referred to the floral organs as transformed leaves, but it is quite as reasonable to suppose that the leaves represent floral or reproductive organs that have assumed vegetative functions.[a]

The stamens and pistils of the primitive types of plants are more nearly like those of the advanced types than are the vegetative metamers, showing that evolution has tended more toward the specialization of the vegetative parts. Dimorphic branches represent a somewhat advanced stage of vegetative specialization. A plant with

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[a] Cook, O. F. Origin and Evolution of Angiosperms through Apospory. Proceedings, Washington Academy of Sciences, vol. 9, 1907, pp. 150–178

dimorphic branches has two kinds of vegetative metamers, in addition to the various kinds of floral or reproductive metamers. In the cotton plant, for example, seven principal kinds of metamers might be enumerated: The two kinds that compose the two types of branches, the two kinds whose specialized leaves form the involucre and the calyx, and the metamers of the corolla, the stamens, and the pistils. Some plants, such as Broussonetia, have two kinds of vegetative metamers alternating in the same stem, each alternate internode having only a small leaf.[a]

The diversity of the metamers does not end with the recognition of the different types, for the individual metamers of the various groups are often as distinctly different among themselves as the plants they compose, or even more so. If it be considered that a plant is an aggregate or colony of metamers, it follows that causes of differences between plants are to be sought in the structure or behavior of the component metamers. Plants with dimorphic branches not only have two kinds of vegetative metamers, but have them arranged in separate series. The variations of the higher plants are much more readily appreciable than the variations of the higher animals, because the same character is repeated in the large number of internode individuals that compose the bodies of plants.

The individuality of the internodes and the significance of this fact in the developmental history of plants were appreciated over a century ago by Goethe, the great German naturalist and poet. In his poem on "The Evolution of Plants," the series of changes in the forms of the metamers is traced from the seedling, the process of plant growth being used as an illustration of the general idea of evolution from simple forms of life to more complex.

> Yet it appears very simple, when first we can see the new structure,
> This in the world of the plants is ever the state of the child.
> Growth is continued at once, one shoot coming forth from another,
> Nodes upon nodes towering up, all repeating the form of the first.
> Still they are not quite the same; in manifold ways they are varied,
> Each of the leaves, as you see, develops beyond the preceding,
> Larger, and sharper in margin, as well as more deeply divided.

Not only the differences of the vegetative internodes, but those of the internodes that are modified as flower stalks and floral organs were recognized, as well as the sexual differentiation of the stamens and pistils, though the poem was published in 1790, three years before the announcement of Sprengel's discovery of the fertilization of flowers. Comparison of the series of gradually modified internodes

[a] Other examples of anisophylly have been described by several botanical writers. See Wiesner, J., Studien ueber die Anisophyllie tropischer Gewaeehse, Sitzungsberichte der Mathematisch-Naturwissenschaftlichen Classe, Kaiserliche Akademie der Wissenschaften, Vienna, vol. 103, 1894, p. 625.

in the individual plant with the successive links of the chain of organic development led Goethe to the view that each plant is an evidence of a general law of evolution.

> Every plant will declare it, the law of the endless creation,
> Every flower will repeat it, louder and louder the voice.

SIMILARITY OF DIMORPHIC BRANCHES TO ALTERNATING GENERATIONS.

Darwin also recognized the individuality of the internodes of plants, though apparently without attaching an evolutionary significance to the fact, no reference being made to it in "The Origin of Species." Attention has been called by Mr. Argyle McLachlan to an interesting paragraph in another work, in which Darwin draws a comparison between the leaf buds of plants and the individual animals that build up the branching colonies of zoophytes:

> The examination of these compound animals was always very interesting to me. What can be more remarkable than to see a plant-like body producing an egg, capable of swimming about and of choosing a proper place to adhere to, which then sprouts into branches, each crowded with innumerable distinct animals, often of complicated organizations. The branches, moreover, as we have just seen, sometimes possess organs capable of movement and independent of the polypi. Surprising as this union of separate individuals in a common stock must always appear, every tree displays the same fact, for buds must be considered as individual plants. It is, however, natural to consider a polypus, furnished with a mouth, intestines, and other organs, as a distinct individual, whereas the individuality of a leaf bud is not easily realized; so that the union of separate individuals in a common body is more striking in a coralline than in a tree. Our conception of a compound animal, where in some respects the individuality of each is not completed, may be aided by reflecting on the production of two distinct creatures, by bisecting a single one with a knife, or where nature herself performs the task of bisection. We may consider the polypi in a zoophyte, or the buds in a tree, as cases where the division of the individual has not been completely effected. Certainly in the case of trees, and judging from analogy in that of corallines, the individuals propagated by buds seem more intimately related to each other than eggs or seeds are to their parents. It seems now pretty well established that plants propagated by buds all partake of a common duration of life, and it is familiar to every one what singular and numerous peculiarities are transmitted with certainty by buds, layers, and grafts, which by seminal propagation never or only casually reappear.[a]

It is plain from this passage that Darwin considered the internodal structure of plants as a method of vegetative propagation of new individuals rather than as an example of successive stages of evolutionary progress. This becomes the more evident from his comparison of the results of vegetative propagation with those obtained by sexual reproduction. The general tendency to uniformity among vegetative individuals lends greater significance to differences that

[a] Darwin, Charles. Journal of Researches, end of chapter 9.

regularly appear among vegetative internodes of the same plant. Dimorphic branches and similar specializations show that change of characters in vegetative internodes is a definite phenomenon in the development of plants, like changes that take place during the development of many animals. Much evolutionary importance has been attached by zoologists to the recapitulation of ancestral characters in embryos, as well as to metamorphosis and alternation of generations. All of these phenomena find their parallels among plants, though botanists have given them relatively little attention.

The evolutionary development of the various degrees of specialization of the branches of such a plant as the cotton becomes more comprehensible if we compare it with the stages through which a simple herb would naturally pass in attaining the stature and habit of a branching shrub or tree. Many small herbs bear single terminal flowers, but in plants that have increased in size and complexity terminal flowers are replaced by axillary flowers or flower clusters, and these tend in turn to grow out into branches, able to subdivide still further and bear larger and larger numbers of flowers.

In the cotton plant the primary branches have now become as sterile as the main stem, and the extra-axillary branches that normally bear the fruit also have the power of changing over into sterile limbs, the production of fruit being deferred to a later generation of branches to enable the plant to construct a larger vegetative framework.

The main stem and the one or more series of vegetative branches which intervene between the germination of the seed and the formation of another flower correspond to several generations of the vegetative parts of a simple herb and might also be compared to the vegetative generations of the plant lice and other lower animals that are able to propagate for several generations by simple vegetative subdivision, instead of requiring sexual reproduction for each generation of new individuals, as among the higher animals. The relations between the sterile and the fertile branches of cotton and of other plants that have dimorphic branches afford a rather close parallel to the original examples of the phenomenon of alternation of generations, though they are not comparable to the changes that occur in the life histories of the liverworts, mosses, and ferns which botanical text-books commonly describe as alternation of generations.[a]

A shrub or tree may be thought of as a colony or complex of many individual branches each corresponding to a separate plant in a species of smaller shrubs or herbs. Dimorphism of branches means that there are two kinds of these branch individuals that follow each

[a] Cook, O. F., and Swingle, W. T. Evolution of Cellular Structures. Bulletin 81, Bureau of Plant Industry, U. S. Dept. of Agriculture, 1905.

other in definitely alternating sequences. The seeds of the cotton, coffee, and many other species do not grow at first into plants similar to the branches which produced the seeds. The seedlings at first develop upright sterile stems and a series of vegetative branches. Another type of branches is formed for the production of flowers and fruit, and then there may be no return to the condition of the upright main stem and the purely vegetative limbs except by way of the seed and seedlings.

In some plants the formation of different kinds of vegetative internodes is more specialized in relation to time, the whole plant going over from one habit of growth or form of foliage to another. In the eucalyptus and in many coniferous trees related to the juniper there is a juvenile form of foliage altogether different from that of the adult trees. This phenomenon is not to be confused with the simpler dimorphism of branches shown in the tropical crop plants, though some of the Coniferæ have this as well as the other. Cuttings of lateral branches, not being able to replace the main axis, do not reproduce the form of the parent tree. Some of the Coniferæ produce a juvenile type of foliage only in exceptional cases of bud reversion, which may even be confined to buds forced from the axils of the cotyledons, as explained by Beissner and Beyerinck.[a]

DIFFERENT TYPES OF DIMORPHIC BRANCHES.

It is easier to describe and compare the dimorphic forms of branches in the several species of cultivated plants if we consider in advance a general difference of function. Some branches have the same form and functions as the axis or main stem of the plant, while others are more or less restricted to the bearing of fruit or to other special purposes. The specializations of the branches show various directions and degrees in different species and varieties of plants, but in each case it is possible to distinguish between branches that are more similar to the main trunk and those that are less similar.

In the present report the word " limb " is used as the general name for branches that are unspecialized or that are specialized for vegetative functions instead of for fruiting. The limbs continue the growth and share the functions of the trunk or main stem of the plant.[b] Limbs may have vegetative functions only and may be

[a] Beissner, L. Ueber Jugendformen von Pflanzen, speciell von Coniferen, Bericht über die Verhandlungen der deutschen botanischen Gesellschaft, vol. 6, 1888, p. lxxxiii. Beyerinck, M. W. Beissner's Untersuchungen üeber der Retinisporafrage, Botanische Zeitung, vol. 48, 1890, p. 518.

[b] In the diagrams that illustrate the habits of branching in this report the vegetative limbs are drawn in solid lines like the main stem, while the fruiting branches are indicated by broken lines. (See figs. 1–7.)

unable to bear flowers or fruit. Branches that bear fruit may be correspondingly restricted on the vegetative side. Different species and varieties of plants are so unlike that no general principle of classification can be applied except that of distinguishing between the different forms of specialization.

The most useful distinction between limbs and other forms of branches relates to differences of function rather than to the structure or positions of the parts. In the cotton plant, for example, the axillary branches function as limbs, while in the Central American rubber tree they are definitely specialized for fruiting and do not become permanent parts of the tree. They die and drop off after they have borne two or three crops of fruit.

The branches that arise from extra-axillary buds also have their functions reversed in the two cases. In the rubber tree the extra-axillary buds produce limbs but no fruiting branches, while in the cotton plant all the fertile branches arise from extra-axillary buds.

DIMORPHIC BRANCHES OF THE COTTON PLANT.

Though the dimorphism of the branches of the cotton plant is not an extreme case, it may be better to use it as the first example before considering the other tropical plants that are less known in the United States. The differences are more striking in some of the tropical plants, but are no more significant in their agricultural bearings. The distinctions between the two kinds of branches of the cotton plant depend upon position and function rather than upon any very conspicuous differences of form or structure. This may explain why the dimorphism of the branches has continued to be overlooked in so familiar a plant as the cotton, although the difference between ordinary short fruiting branches and large basal branches or "wood limbs" is obvious at a glance and is familiar to all planters.[a]

The cotton plant, as represented by the Upland varieties in general cultivation in the Southern States, consists of a central axis or "stalk" bearing a leaf at the end of each joint or internode. Branches that arise from the axils of the leaves do not normally bear fruit, but behave like divisions of the main stalk. A fertile branch arises at one side, right or left, of an axillary branch or an undeveloped axillary bud which may give rise to an axillary branch late in the season. The position is usually constant throughout in the same stalk, so that the plants can be distinguished as right-handed

[a] For a brief statement regarding dimorphism of branches in cotton, see "Weevil-Resisting Adaptations of the Cotton Plant," Bulletin 88, Bureau of Plant Industry, U. S. Dept. of Agriculture, 1906, pp. 19–20. See also "A Study of Diversity in Egyptian Cotton," Bulletin 156, Bureau of Plant Industry, U. S. Dept. of Agriculture, 1909, pp. 28–30.

or left-handed with reference to the position in which their fruiting branches are borne along the main stalk.

On the fruiting branches this regularity in the position of the flowers is not so obvious, for the joints are twisted to bring all the leaves to the sides and all the flower buds on top. The flower buds appear between the bases of the stipules, sometimes nearer the right-hand stipule, sometimes nearer the left. The stipule that is close to the base of the flower stalk is usually larger than the other.

Antidromy, as the condition of right and left handedness of plants has been called, consists in the fact that the stems of the different individual plants reverse the direction of the spirals in which the leaves and branches are arranged. On some cotton plants the extra-axillary branches occur on the right side of the axillary branches; in other individuals on the left side. If a stalk on which the extra-axillary buds appear to the right of the axillary buds be considered right-handed, the turn of the spiral will pass to the right in going by the shortest route from any given branch to the one above. Thus it appears that the extra-axillary bud is always above the axillary, in the sense that it is farther up the spiral.

In all the different species and varieties of cotton thus far examined right-handed and left-handed stalks seem to be about equally numerous. As the Guatemalan types in which the branch dimorphism was first studied had never undergone close selection, the question was raised whether among the carefully bred American varieties there might not be specializations toward one direction of the spiral. No indication of this was found in a large series of varieties studied by Mr. F. J. Tyler at Waco, Tex. Seeds from the same boll were also found to give about equal proportions of right-handed and left-handed seedlings. The possibility remained that the direction of the spiral may be determined in advance by the positions in which the seeds develop on the placenta. To test this theory seeds from two rows of the placenta were planted separately, but gave right and left handed plants without reference to the position on the placenta. The manner in which this diversity arises remains unexplained.

The axillary buds have been found in all the types and varieties of cotton thus far observed, but they are often very small and dormant. They may all remain undeveloped unless the plant is cut back or severely checked by unfavorable conditions. In many kinds of cotton both types of branches are commonly to be found on the same plant.

The difference between the two kinds of branches was first appreciated in Guatemala in connection with the indigenous Kekchi cotton. The lower joints of the main stem of the Kekchi cotton usually produce two branches, one a fertile branch with flowers and fruit, the

other a sterile limb with leaves only. It was noticed also that the branches that bear the flowers arise in the same position as the flowers themselves—not in the axils of the leaves, but at the side of the axillary bud.

The axillary branches of cotton function normally as equivalents of the main stem in the sense that they do not bear any flowers or fruits except in the indirect way of producing other branches of the fertile sort from extra-axillary buds. Fertile branches borne by the main stem of a cotton plant may be called primary fruiting branches; those that come from limbs may be called secondary fruiting branches. Normal fruiting branches of both kinds bear a flower bud at each node. Secondary limbs may be produced from primary limbs, or even from axillary buds of the fruiting branches, especially if a plant has been injured or pruned or suddenly forced into renewed growth late in the season. Only in rare and abnormal cases is a flower borne directly on a branch that arises from an axillary bud.

It is the normal habit of some varieties to develop vegetative limbs from axillary buds along with the fruiting branches that come from the extra-axillary buds, as in the Kekchi cotton of Guatemala. Some varieties do not have true axillary branches, but develop limbs from the extra-axillary buds of the main stem, the production of flowers being deferred until fertile branches can be produced on the limbs. This is sometimes the case with the Pachon cotton of western Guatemala and with the Rabinal cotton of the central plateau region. In an experiment with the Pachon cotton at Lanham, Md., no axillary limbs were produced, each node bearing only an extra-axillary limb. In another experiment at Trece Aguas, Alta Vera Paz, Guatemala, the Pachon cotton showed nearly the normal habit of the Upland type of cotton, bearing most of its crop directly on fertile primary branches, sending out small primary limbs only in the latter part of the season.

In the Old World cottons (*Gossypium herbaceum*) and the Sea Island cottons it is not usual for the plants to develop true axillary limbs to functional size. If the other branches are injured or stunted, the axillary limbs may push out a few leaves.

In the Egyptian cotton, also, there is a very general tendency to develop vegetative limbs as well as the fertile branches from extra-axillary buds. The axillary buds usually remain dormant unless an injury or other abnormal condition forces them into growth. At the base of the main stalk it is often difficult to see that the limbs come from extra-axillary buds, but a little farther up it becomes obvious that both the limbs and the fruiting branches have extra-axillary positions on the same side of the axillary bud, with much regularity. Finally, some varieties of Upland cotton may not form

any vegetative branches, though extra-axillary limbs and even axillary limbs may be formed by the same varieties when grown under conditions that favor a large development of the vegetative parts.

In the so-called "cluster" cottons it often happens that one or more buds, or bolls, appear to be borne on short axillary branches, but careful examination will usually show that the fruit does not come directly from the axillary branch itself, but belongs to a very short fertile branch arising from the axillary. In the Egyptian cotton a short fertile branch is often pushed out from one side of the dormant bud that represents an undeveloped axillary branch. Sometimes the bud that represents an undeveloped axillary branch is carried up a little on the base of the extra-axillary branch. After this has occurred, a branch that arises from the axillary bud appears to be borne by the extra-axillary branch rather than by the main stem of the plant. This impression may be strengthened still further if the axillary bud or the fruiting branch to which it sometimes gives rise be changed into flower bud, as in the cluster cottons that show an abnormal propensity toward fruit production. Sometimes the normal extra-axillary fruiting branch is also replaced by a single flower bud, so that three flower buds may appear to come from each of the nodes of the main stem instead of the more normal complement of a limb and a fertile branch.

In varieties of cotton that are not inclined to produce true axillary limbs, the extra-axillary branches usually assume the functions of limbs; that is, they produce flowering branches instead of bearing the flowers themselves. A true axillary limb seldom stands alone on the main stem, but is almost invariably accompanied or preceded by a fertile branch. The insertion of a limb and a branch close together, at the same node, makes it easy to ascertain whether true primary limbs are present or limbs that represent fruiting branches transformed for vegetative purposes.

The leaves of the vegetative limbs and those of the main stem are larger and have relatively longer petioles than those of the fruiting branches. Another definite difference between the leaves of the main stem and those of the fertile branches has been noticed by Mr. Rowland M. Meade in the Triumph variety of Upland cotton. The leaves of the main stem have nectaries on three of the veins, while those of the fertile branches have only the one nectary, on the back of the midrib. When the fruiting branches are shortened, as often happens in the Egyptian cotton, the petioles of their leaves are also greatly reduced in length, a step toward the still more distinctly abnormal condition where the leaves of the shortened fertile branches begin to show some of the characteristics of the involucral bracts.

In types of cotton that have a normal development of branches an axillary bud yields only a sterile vegetative branch or limb. From extra-axillary buds three things may come: (1) Flowers, (2) fertile branches bearing a series of flower buds, one at each node, and (3) extra-axillary limbs having the position of fertile branches but sharing the form and function of the axillary limbs.

VARIOUS FORMS OF FRUITING BRANCHES.

As the fruiting branches represent a specialized feature of the cotton plant, it is not surprising that different stages of specialization are found in the fruiting branches of the various species and varieties of cotton. Though the general distinctions between the vegetative limbs and the fertile branches apply to all forms of cotton thus far examined, definite differences often appear between the fruiting branches of different varieties and even among the individual members of the same variety; and since these differences in the methods of producing the fruit are of direct agricultural importance, it is worth while to understand them in detail.

In a general botanical sense it might be said that the fruiting branches of all kinds are intermediate between the vegetative limbs and the flowers, for botanists consider that each flower of a plant represents a shortened branch. The range of specialization of fertile branches lies, therefore, between the limb and the flower. The fertile branches of some cottons are long and leafy, much like the vegetative limbs, while in others they may be so much shortened as to appear merely a part of the flower stalk. In the great majority of cases the fertile branches are definitely unlike either of the extremes, but the range of forms is completely covered if the whole series is considered.

A comparison of the branches of the Egyptian cotton with those of the Kekchi cotton or with our United States Upland varieties may serve as an illustration of the different degrees of specialization found in the branches in different types of cotton. In the Egyptian cotton the basal joints of the fruiting branches are longer than in the Upland, while on the vegetative branches the basal joints are shorter than on the corresponding branches of the Upland. In other words, the differences between the basal joints of the two kinds of branches are much greater in the Egyptian cotton than in the Upland series. The tendency for the basal joint of the fruiting branches to be longer than the others is very general, and likewise for the basal joints of vegetative branches to be shorter, but in the Egyptian cotton the contrast is more accentuated than usual.

The Hindi cotton that figures in literature as a contamination of the high-grade Egyptian stocks shows the slightest differentiation of the fruiting branches. These branches have a curious zigzag form that readily distinguishes them from the straight vegetative limbs, but they may retain the nearly upright position of the limbs and do not appear to have lost any of the vegetative functions. In such cases the flower buds are usually aborted at an early stage, though mature bolls are sometimes found on branches that remain more upright and limblike than those in Upland or Egyptian varieties.

The other extremes of differentiation in the direction of the shortening of the fruiting branches are found in great variety among the so-called " cluster " cottons. The simplest form of clustering is represented by a mere shortening of the joints of the fruiting branches, which brings the flowers and bolls closer together than in normal long-branched varieties. More pronounced clustering leads to denser groupings of bolls by the development of additional flowers on short branches from the axils of the leaves of the fruiting branches. In its most extreme form the clustering has the effect of reducing the number of bolls. The leaf buds that normally continue the growth of the branches are sometimes replaced by flower buds, or adjacent leaf buds may be aborted and fall off, so that the branch soon ends with a flower or a boll and no more joints can be added.

It usually appears that the cluster habit is merely a form of specialization of the fruiting branches, for the vegetative limbs and axillary branches are usually not affected at all by the cluster tendency. In other cases the axillary buds of the vegetative branches, as well as the terminal buds, may appear to be replaced by flower buds, though it is usually found, on closer examination, that the flower bud is borne on a short fertile branch that rises from an otherwise abortive axillary branch.

Finally, it sometimes happens, as in the Triumph variety of Upland cotton, that two forms of fruiting branches are regularly produced. The normal condition with the Triumph cotton is to have several of the lower fruiting branches very short and determinate, so that sometimes this variety is erroneously described as a cluster type.

STERILITY OF INTERMEDIATE FORMS OF BRANCHES.

Botanists are familiar with the fact that changes and substitution of form often occur among the floral organs of plants. The most familiar change of this kind is in the so-called doubling of flowers, meaning the addition of a larger number of petals to the corolla. In many cases the number of stamens decreases as the petals become more numerous, and many double flowers are completely sterile, both the stamens and pistils being transformed into petal-like organs.

Such changes are occasionally found in the flowers of the cotton plant, as when additional petals are inserted on the staminal tube. Sometimes these additional petals are very small, as though individual stamens had been changed into petals. More serious modifications appear when petals of nearly normal size are inserted on the base of the staminal tube, which is then subdivided into five separate columns alternating with the supernumerary petals. Pistils are sometimes transformed into supernumerary petals, though the change is seldom complete. Some of the pistils usually remain unmodified, but the boll is deformed and seldom develops to maturity.

In view of the occurrence of intermediate conditions between the parts that are so profoundly different as the stamens and pistils, it would naturally be expected that intermediate stages would also occur between the two forms of branches, in spite of the fact that dimorphism represents the normal condition. Intermediate forms of branches do occur, and, like the intermediate forms of the floral organs, they are usually sterile. Not only do most of their flower buds abort, but the branches themselves commonly fail to reach full development. They often wither and fall off after producing one or two internodes.

If such branches occurred without regularity on the plant, it might be difficult to determine the nature of the abnormality, but they have evident relations to particular varieties and to definite positions on the plants. In following the branching habits of the Egyptian cotton through the season of 1909, Mr. McLachlan noticed the curious fact that an interval of rudimentary or abortive branches usually occurs on the main stem of the plant, consisting of two or three internodes above the last of the sterile vegetative branches and below the first normally developed fruiting branch. Even on large plants that bear limbs 4 feet or more in length, with 30 internodes and upward, and fruiting branches nearly 2 feet in length, composed of twelve internodes, the intervening nodes are either quite vacant or have branches only a few inches long, usually with only one internode, very seldom with more than two or three. Sometimes there is a more gradual transition from these small branches to those of normal length, but there is a strong tendency to abortion of the flower buds on all of the shortened lower branches of the fertile form.

As already suggested, the frequency of abnormal branches in the Egyptian cotton may be connected with the contamination of the Egyptian stocks with the so-called Hindi cotton, a type related in some respects to our United States Upland cotton, but widely differing in others. Though the Hindi cotton has the two distinct forms of branches, they appear less different than in any other variety included in the experiment. It seems to be the regular habit of Hindi

cotton to shed a large proportion of its flowers in the very young stages and then to develop the vegetative functions of these barren fertile branches which not only grow to large size, but often produce branches of their own from axillary buds. In view of these habits of the Hindi cotton, it does not appear improbable that the frequent tendency of the Egyptian plants toward abnormal, intermediate forms of branches is caused, or at least intensified, by admixture with the Hindi type. In any case the characters of the branches must be taken into account as one of the standards of selection in the Egyptian cotton, as well as in Upland varieties.

In addition to the relatively small and late development of the fruiting branches on vigorous, overgrown Egyptian plants a very large proportion of the flower buds are aborted and fall off. Many of them are dropped while still very small and even microscopic in size. This abortion of the buds appears to have a definite relation to the habits of branching of the plants. If the fruiting branches are of a normal, slender, and horizontal form, the chances of the buds being retained are very much greater. If, on the other hand, the fruiting branches become more robust and take an oblique or upright direction and thus resemble the vegetative branches or limbs, the buds almost invariable fall off while still very young. Only the scars of the fallen buds may remain as a distinction between the fertile and sterile branches, as in the Hindi cotton. On different plants and even on different branches of the same plant, the buds attain different sizes before they abort and fall off, and these different sizes of the buds may be considered as marking intermediate stages between the normal fertile branches which retain their fruit and the normally sterile vegetative branches which produce no trace of flowering buds.

The practical point is that these intermediate conditions and forms of the branches, even when they bear large numbers of buds, produce very little fruit, often none at all. The failure of a plant to maintain the normal specialization of the two forms of branches is an undesirable character from the standpoint of acclimatization and breeding. There is not only a tendency on the part of the newly imported plants to increase the number of sterile vegetative branches at the expense of the fertile, but a tendency for the remainder of the fertile branches to become abnormal.

While it is possible for a very large and vigorous plant to produce a good crop of cotton with a sufficiently long season, there can be no regular assurance of large yields unless the plants begin to bear early in the season. The plants must begin to produce fertile branches early in the season and numerous buds on each branch. It is not to be expected that all of the buds of a fertile plant will set bolls, or that all the bolls will reach maturity, but this only makes it the more

important that the plants shall be able to produce enough flower buds to take advantage of all opportunities for the setting of a large crop. The tendency of the Egyptian cotton to grow larger vegetative branches and smaller fruiting branches than the Upland cotton is responsible for differences in yield and earliness between the two types.

In Egypt and in the cooler parts of the United States the Egyptian cotton produces small, early plants with much the same habit of growth as the Upland cotton. The more fertile soils and the greater heat of the spring months in the Southwestern States induce a much more luxuriant growth, especially in the Egyptian cotton. The plants not only shoot up to a very large size, but put forth many vegetative branches from the base of the stalk before any fertile branches are formed.

INTERMEDIATES BETWEEN FERTILE BRANCHES AND FLOWERS.

Farther toward the top of the plants another intermediate condition of the branches is frequently found, especially in the Egyptian cotton. The fertile branches become abnormal by approximation to flower buds. The leaf bud that would continue the growth of a normal fruiting branch either becomes abortive or appears to be directly transformed into a flower bud. A further evidence of the abnormality of these branches is found in the fact that their leaves are usually different from those of normal fruiting branches and tend to take on the form of the floral bracts. The first and most frequent manifestations of this tendency are found in the shortening of the petiole or stem of the leaf and the enlargement of the stipules—the small, pointed, leaf-like structures at the base of the petiole. (See Pl. I.)

On the normal fruiting branches the stipules are always shorter than those of the main stem or vegetative limbs, remaining narrow and pointed; but on the abnormal, shortened, fruiting branches one or both of the stipules become broadened and thickened as in the formation of the floral bracts. In Egyptian cotton it is easy to find all these abnormal fruiting branches completing a series of gradations between normal leaves or completely modified floral bracts. That the abnormality of the branches involves in this case the breaking down of the distinctions between the internodes of normal fruiting branches and those of the more specialized floral organs is also shown by the fact that leaf-like bracts are often found as well as bractlike leaves, and that supernumerary petals, divided staminal tubes, and abnormal pistils are of frequent occurrence on plants that show abnormal intermediate forms of branches.

Each of the three bracts that inclose the bud of the cotton plant represents a specialized leaf formed by enlarged stipules united with a greatly reduced blade. In Egyptian cotton it often happens that the leaf subtending a flower bud does not retain its normal size and shape, but becomes more or less intermediate between a leaf and a bract. One or both of the stipules may be enlarged and united with the blade, or the blade may remain separate, with the stalk more or less shortened.

The formation of these abnormal organs shows, as in the case of the branches, a failure to maintain the normal specialization of the parts. The processes of growth that should take place only in the bracts are partly anticipated in the formation of the leaf, the result being an intermediate expression of the leaf and bract characters. Plants that have the bractlike leaves are also likely to have leaf-like bracts, more deeply divided at the apex than the normal bracts, and often deeply lobed or cleft nearly to the base.

The liability of the normal specializations to break down may be connected in a general way with the fact of dimorphism of the branches. The fertile branches can be looked upon as inflorescences that have approached the vegetative form and tend to revert to more determinate conditions. The dimorphism of the branches, in such plants as cotton and coffee, means that there are two kinds of vegetative internodes, one forming branches devoted to purely vegetative purposes, the other somewhat intermediate between vegetative and reproductive internodes. Individual internodes which are accessory to the reproductive internodes occur in many plants, just below the flowers. The fruiting forms of specialized branches are made up of such intermediate or slightly specialized internodes.

The practical significance of the abnormalities of the involucre is the same as in the case of the branches. The disturbance of the normal processes of growth are shown to have affected more than the mere external form of the plants. The flower buds that follow the abnormal bractlike leaves are almost invariably aborted, and if the number of such abnormalities is large the plant becomes unproductive or even completely sterile. Such abnormalities have been particularly abundant in the Dale variety of Egyptian cotton, both in 1908 and 1909, but the 1909 planting from seed raised in Arizona in 1908 shows a much larger proportion of normal individuals than among the plants grown from imported seed. Some of the plants of the Dale cotton have the strict upright form of the so-called limbless varieties of Upland cotton, and some produce no flower buds in the normal place on fruiting branches, but only from buds of short axillary branches that appear to represent transformed leaf buds, all other buds being completely aborted. Sometimes all of the buds abort and the whole plant remains completely sterile.

An apparent transformation of the axillary leaf bud into a flower bud is of frequent occurrence in some of the cluster varieties of Upland cotton, but is also common in Egyptian cotton, especially in the Dale variety that has the abnormal branches and bracts.

A transformation of leaf buds into fruiting buds might be expected to increase the fertility of the plants, but this is not the result in the Egyptian cotton for the reason that the most frequent effect of this transformation is to put an end to the growth of a fertile branch. A growing branch must have a leaf bud at the end, and if this terminal bud is transformed into a flower, the branch does not continue. If the transformation is successfully accomplished, we secure one additional boll, but at the expense of a fertile branch which might produce several bolls. The loss is still further increased by the fact that the plants addicted to this habit of transforming leaf buds into flower buds lose a very large proportion of their buds by abortion.

The frequency of abnormalities in the bracts and in the floral organs shows a general disturbance of the normal process of heredity in the newly imported varieties, such as frequently attends hybridization. In the Egyptian cotton varieties it does not appear that these phenomena are directly connected with hybridization, for they occur in large numbers of plants that give no evidence of admixture of Hindi or Upland characteristics. Nevertheless, the whole series of abnormalities may be considered from the standpoint of hybridization, in that they represent intermediate stages between organs of the plants that are normally distinct and different from each other. In each case there is a failure to follow the normal paths of development by which the normal individual advances from the characters of the seedling to those of the adult plant. Although a plant may have all of its characters normally developed in some of its parts, the parts that show the intermediate conditions of the characters may be quite as abnormal as in any hybrid, and resulting sterility is quite the same from the practical standpoint.

The study of the evolution of plant structures has led to the recognition of a phenomenon called translocation of characters, or homœosis, the carrying over into one part of the plant of a character that normally appears in another part, such as the manifestation of the bract characters by the next leaf below the bracts in Dale cotton.[a]

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[a] Leavitt, R. G. A Vegetative Mutant and the Principle of Homœosis in Plants, Botanical Gazette, January, 1909, p. 64.

"In homœosis a character or a system of organization which has been evolved in one part of the body is transferred ready-made to another part. The great mass of instances are of the class called teratological. By this designation we mean substantially that they are suddenly appearing deviations from the customary structures."

In extreme cases a single long-stemmed boll may arise from the axil of a leaf at the base of the fertile branch. This might be taken to indicate a direct transformation of the axillary bud into a fertile branch; but further examination will usually show, even on the same plant, great variation in the pedicels of these axillary bolls, making it evident that they are not simple pedicels, but shortened branches. Small bractlike leaves or stipules are occasionally present, even on straight stems, and sometimes the joint between the branch proper and the true stem or pedicel of the boll remains distinct, even when there are no leaves or stipules. (See Pl. II.)

Where the axillary branches are longer and more definitely jointed it becomes possible to see that the bolls are really borne on a short fertile branch that rises in turn from a short true axillary branch, instead of being inserted directly on the main stem. A shortened axillary branch may represent three normally independent elements, an axillary vegetative branch, a secondary fertile branch borne on the axillary, and the pedicel of the boll, all fused into a simple stem. In some cases it is plain that the true axillary branch has remained entirely undeveloped, for an axillary bud or bud scar can often be found at the base of one of the shortened branches. When no such mark is found it may be supposed that the axillary bud was carried out by the growing branch. It is seldom necessary to suppose that the axillary bud is directly transformed into a flower bud, since the existing conditions can also be reached by fusing the successive joints together, much as they are fused in the formation of a normal involucre.

The idea of translocation may be applied to these abnormalities of the Egyptian cotton, or it may be combined with the idea of hybridization, in view of the many intermediate stages between the parts that are normally quite unlike. The fact that sterility so generally accompanies these intermediate conditions is a further reason for looking upon translocation as a phenomenon akin to hybridization. Changes that might be looked upon as results of partial translocations of characters might also be considered as hybrid metamers or metameric hybrids. They represent abnormal intermediate stages between metamers that are quite unlike when normally developed. They indicate an abnormal intermediate expression of the characters rather than an abnormal transmission of characters to new parts of the plant. All of the hereditary characters are probably transmitted to all parts of the plant, since all of the internodes are able, directly or indirectly, to produce flowers and seeds, but the growth of the normal plant involves the full expression of each character in the appropriate place and its complete suppression in other parts of the plant. Failure of the proper suppression of a character

amounts to an abnormality, no less than the failure of a character to come into expression.

These abnormal intermediate forms of branches might also be compared to the hermaphrodite individuals that occur occasionally in plants that normally have the stamens and pistils on separate individuals, such as the fig tree, the date palm, and the hop vine. The diœcious habit is a condition of dimorphism inside the species. The abnormalities of the intermediate individuals support the analogy with hybridization. The behavior of hermaphrodite hop plants has been studied recently by Dr. W. W. Stockberger.[a]

These phenomena are of interest from the standpoint of the study of heredity as well as for agricultural purposes, since they show that characters having little or no direct relation to the external conditions may be seriously affected by changes of environment. New conditions appear to disturb the functions of heredity, not only to bring about substitution of characters and thus cause diversity between the plants, but they also appear to break down specializations inside the plant, to disarrange the patterns, as it were, of the different kinds of internode individuals that form the normal plant.

This conclusion does not refer alone to the fact that these abnormalities are very frequent in the newly imported varieties of cotton, but is also justified by the fact that different parts of the same field may differ distinctly in these respects, as the result of relatively slight differences of external conditions. Even in hybrids that are showing Mendelian segregations of parental characters of branching in the second generation, experiments in different places may give very different results. Hybrids between the Kekchi cotton of Guatemala and the Triumph variety of United States Upland cotton showed, in one place (Del Rio, Tex.), many Triumph-like plants with short basal branches, while at another place (Victoria, Tex.),

[a] Stockberger, W. W. Some Conditions Influencing the Yield of Hops, Circular 56, Bureau of Plant Industry, U. S. Dept. of Agriculture, 1910, p. 11.

"In some sections hop vines are occasionally found which bear both staminate and pistillate flowers. Such plants are known locally as 'bastards,' 'mongrels,' or 'bull-hops.' When they occur they represent a total loss, so far as yield is concerned, since the few hops borne by these vines are inferior and never gathered. On the acre under consideration there were only five of these plants, but they have been observed in much greater proportion in other years and in other localities * * *. In 1908 a number of cuttings were taken from one of these 'bastard' plants and removed to a locality about 40 miles distant. The vines from these cuttings came into flower in 1909 and in every case reproduced the malformation of the original plant from which they were taken. In view of this fact care should be taken to prevent the use of cuttings from 'bastard' plants by promptly digging them out and destroying the roots as soon as they are observed. In this way their perpetuation may be prevented and the loss in yield due to their occurrence avoided."

the same stock of hybrids showed only long branches like the Kekchi parent. Hybrids between Kekchi and McCall, on the other hand, growing beside the Triumph hybrids, showed the short "cluster" branches of the McCall parent very definitely in both localities, and in approximately Mendelian proportions. In the equable tropical climate of Guatemala a planting of the McCall cotton failed to give any indication of the cluster habit that characterizes this variety in the United States.[a]

The frequency with which the abnormal intermediate forms of branches occur in all the different stocks of Egyptian cotton that are now being grown in Arizona increases the practical importance of this class of facts. The behavior of other types of cotton during the period of acclimatization has shown that new conditions of growth are able to disturb the processes of heredity and thus lead to many abnormalities of development and often to the complete sterility of the plants, either through failure to form any flower buds or through the abortion of all that are formed.

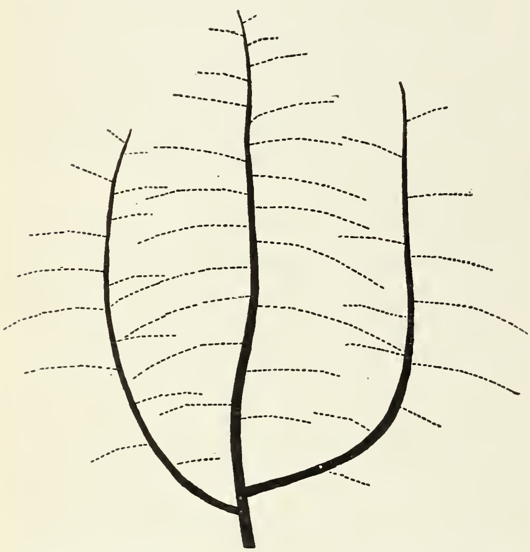


FIG. 1.—Diagram of a cotton plant with two vegetative branches and numerous fruiting branches.

Whether the production of these abnormally shortened branches of the Egyptian cotton is connected with the transfer to new conditions is not so plain as in the case of the abnormal transformations of fruiting branches into vegetative branches, but it is quite possible that the two conditions merely represent the extremes of one long series of variations. In the Dale cotton as grown near Yuma, Ariz., in 1909, the abnormal shortening and abortive tendencies of the branches were much stronger in the plants raised from imported seed than in those produced from seed raised at Yuma in 1908. The larger and more luxuriant plants also showed the greater tendency to abnormal shortening of the fruiting branches, instead of the usual tendency to elongate and change to the vegetative

[a] Cook, O. F. Suppressed and Intensified Characters in Cotton Hybrids, Bulletin 147, Bureau of Plant Industry, U. S. Dept. of Agriculture, 1909, p. 23.

form. The analogy with the cluster habit of Upland varieties is often very strong, and in these also the tendency to abortion of the flower buds is often very great. Under favorable conditions cluster varieties of Upland cotton are sometimes extremely productive, but if unfavorable conditions supervene they are liable to wholesale abortion of the flower buds or the young bolls. The very strong tendency to fruitfulness defeats itself. The plant is under too great a strain of production and suffers the more acutely if conditions become unfavorable.

RELATION OF DIMORPHIC BRANCHES TO ACCLIMATIZATION.

The recognition of the different behavior of the two forms of branches is an essential step in the scientific study of many of the problems of cotton culture. One of the most striking illustrations of the significance of the dimorphism of the branches has been shown in the study of acclimatization. Central American varieties of cotton that grew under their native conditions as low, short-stalked plants with few limbs and numerous horizontal, fertile branches (fig. 1) showed in Texas a complete change of habits of growth, becoming large, densely leafy bushes, with many strong, sterile limbs, but with very few fruiting branches or none at all. (Compare figs. 1 and 2.)

Fig. 2.—Diagram of a cotton plant with numerous vegetative branches and no fruiting branches.

If the change had affected only the size of the plants, it could have been looked upon as a direct result of a rich soil or more favorable conditions of growth, but the complete unlikeness of the Texas plants to their Central American parents showed that other factors were involved. It was possible to raise large-sized plants which still retained the normal form and fertility of the type. The abnormal behavior of the plants was found to arise largely from the fact that sterile limbs were substituted for the normal fruiting branches.

The most extreme result of the transfer to new conditions is shown when the plants fail to form any fruiting branches, all the branches being changed over to the vegetative form (fig. 2). Such plants, of necessity, remain completely sterile, there being no place where fruit can be put on, in spite of the most luxuriant vegetative growth. Where the reaction is less violent the plants are not completely sterile, but produce a late crop, often cut off by frost before any of the seed has ripened (fig. 3). Even when the plants are all able to ripen seed the crop may be cut short and the quality rendered inferior because too many vegetative branches are formed and the bolls develop too late in the season.

A gradual return of the plants to their normal habits of branching has marked the progress of acclimatization. The fertility of the imported stocks has also continued to increase so that many varieties of the Central American cottons are now able to grow in Texas in a completely normal manner, under the same conditions that render plants of the same stocks abnormal and unfruitful if grown from imported seed.

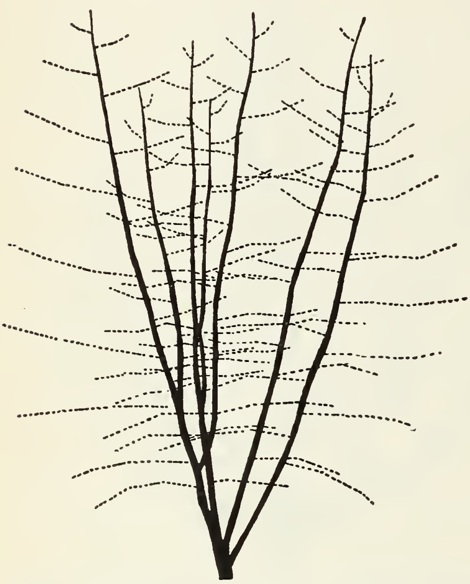


Fig. 3.—Diagram of a cotton plant with six vegetative branches and numerous fruiting branches.

The relation of the factor of branch dimorphism to the problem of acclimatization that first became apparent in dealing with the Kekchi type of Upland cotton from Guatemala has been shown in differing degrees in many other types, including the Egyptian that has been introduced into Arizona and southern California. In all such cases the reduction of the vegetative branches may be looked upon as one of the measures of acclimatization, since it represents a better adjustment to the new conditions. The collection of statistical data on this point in connection with the Egyptian cotton was entrusted to Mr. Argyle McLachlan. A report of his observations on Egyptian cotton growing in the Yuma Valley in the season of 1909 shows very definite contrasts in the production of vegetative branches. Newly imported stocks of Mit Afifi cotton usually produced the first fruiting branches on the fifteenth or sixteenth

node of the main stalk, while an acclimatized stock of the same variety began to produce fruiting branches at the tenth node, on the average.

To secure a further reduction of the vegetative branches must be considered as one of the principal problems of adaptation in connection with the establishment of an Egyptian cotton industry in the United States. Experiments have demonstrated that good crops of Egyptian cotton can be grown in Arizona, but the large, branching plants greatly increase the labor of picking and much of the crop is likely to be damaged or lost. The heavily laden branches are very brittle and many of them are broken by the wind or by the pickers. Very large plants are often a total loss, for even the main stalk is likely to break after two or three large branches have split off. Stalks with no vegetative branches very seldom break.

A recent study of cotton culture in Egypt shows that the native method of very close planting is an important factor in restricting the growth of vegetative branches, but the scarcity of hand labor would forbid a direct imitation of the Egyptian system in the United States. Experiments are now to be made with modified systems of close planting adapted to machine culture. It may prove desirable to leave three or more plants in a hill, instead of one, if the vegetative branches can be suppressed in this way. Attention is also being given to the selection of early, productive plants with few vegetative branches or none. Varieties of Upland and Sea Island cotton have been developed which seldom produce any vegetative branches.

RELATION OF BRANCH DIMORPHISM TO WEEVIL RESISTANCE.

Cotton varieties that develop the extra-axillary vegetative branches instead of the axillary limbs are very poorly qualified for early fruiting and determinate habits of growth, which have been considered as means of avoiding the injuries of the boll weevil. One of the difficulties of combating the weevil by cultural methods lies in the fact that our Upland cottons continue to produce a succession of superfluous buds, in which weevils are bred throughout the growing season. If the weevils did not have a succession of buds to feed upon, breeding would diminish in the latter part of the season, and the number that could survive the winter would be greatly reduced. The pollen diet seems to be absolutely necessary to enable the weevils to complete their life history. Until they have fed upon pollen the adults very seldom copulate and never lay eggs.

Of all the types thus far known, the Kekchi cotton of Guatemala comes the nearest to the ideal of a determinate habit of growth, for it is able by means of its ready development of axillary limbs to secure abundant foliage without being compelled to continue the for-

mation of flowering buds. Varieties which have no vegetative limbs have no leaves except those of the main stem and the fruiting branches. Fruiting branches produce only as many leaves as flower buds, a bud at the base of each leaf. Varieties that do not produce vegetative branches must put on more flower buds in order to produce additional leaves.

Even when the weevils are not present a large proportion of the buds and young bolls of our Upland cottons are generally thrown off as superfluous, the vegetative energy of the plant not being adequate to bring them to maturity. Selection has probably tended toward the elimination of sterile branches in our Upland types of cotton. As long as the weevils did not enter into the problem, the superfluous buds, though no doubt causing a large waste of the productive energy of the plant, had a compensating value as a kind of insurance of the crop, for if in an unfavorable season the early buds were lost their places were filled by numerous successors as soon as the weather improved.

With the advent of the weevil it becomes a matter of importance to do away, if possible, with this persistent prodigality of bud formation. At the same time it is essential that the growth of the plant continue, at least to the extent of producing leaves enough to serve adequately the purposes of assimilating food for the growth of the bolls. The Kekchi cotton, by making use of primary branches, suggests a factor that has a relation to the problem, by showing how more foliage can be produced without the need of making the extra number of floral buds which are likely to serve only as breeding places for the weevils.

Many other kinds of plants, the great majority, indeed, have the determinate habits which would be so great an advantage in cotton in dealing with the weevil, for they produce buds and blossoms for only a short interval. Some plants can be made to continue in blossom by having their flowers picked so that seed can not set. To have educated the cotton plant to such determinate habits by selection might have proved a difficult and time-consuming labor. But with the realization of the fact that the cotton plant has two distinct kinds of branches, one of which does not produce flower buds, the task of finding or securing by selection a regularly determinate variety of cotton appears more definite and practicable. The possibilities of utilizing at the same time others of the numerous weevil-resisting adaptations possessed by the Kekchi cotton and other Central American varieties have received detailed consideration in a previous report.[a]

[a] Cook, O. F. Weevil-Resisting Adaptations of the Cotton Plant, Bulletin 88, Bureau of Plant Industry, U. S. Dept. of Agriculture, 1906.

The application of branch dimorphism to the problems of weevil resistance is not necessarily limited to early fruiting and determinate habits of growth. While early fruiting is undoubtedly an advantage under the ordinary conditions of cotton-growing communities, it does not necessarily follow that late-fruiting types of cotton will be permanently excluded from cultivation in all weevil-infested regions. Late-fruiting varieties must always suffer worse, of course, when grown with early varieties, but if the late-fruiting varieties were grown exclusively by whole communities the disadvantage would be less and might be avoided entirely if varieties were secured which were able to set a crop of bolls within a short time after the production of flower buds began. As long as the weevils were left without pollen to feed upon, and were thus unable to breed, the danger from weevils would not be increased. A quick-fruiting late variety, grown by itself, would have the same advantages of weevil resistance as an early variety grown under ordinary conditions, and with the prospect of being able to set a larger crop of bolls than the small plants of an extra-early variety.

DIMORPHIC BRANCHES OF THE CENTRAL AMERICAN RUBBER TREE.

The differences between the two kinds of branches in the Central American rubber tree (Castilla) correspond in some respects to those of the cotton plant. All the flowers and fruits are borne by one kind of branches, while the other kind has vegetative functions only, like the main trunk of the tree. But with regard to the origins of the two kinds of branches, the rubber tree is directly contrasted with the cotton plant. The fertile branches of Castilla always come from axillary buds, while the vegetative branches are always extra-axillary.

The diversity of function is carried a step farther than in the cotton plant, for the fertile branches do not become a permanent part of the tree. After they have borne two or three crops of fruit they separate neatly from the trunk and drop out of their sockets, which soon heal over. The dimorphic nature of the branches of the genus Castilla and the self-pruning habit of the fruiting branches have been described and illustrated in a former publication.[a]

Except in very rare instances, the fruit-bearing branches of Castilla remain quite simple and produce only leaves, followed in the next year by a cluster of flowers above each of the leaf axils. Growth takes place only at the end of the branch, leaving a longer and longer

[a] Cook, O. F. The Culture of the Central American Rubber Tree, Bulletin 49, Bureau of Plant Industry, U. S. Dept. of Agriculture, 1903, p. 20, pl. 10.

naked section at the base after the successive crops of leaves and fruits have fallen. Finally the weight of the branch becomes too great for the support, the soft basal joint gives way, and the branch drops to the ground. The base of the branch is conical or rounded, and fits into a socket in the wood of the trunk. Both the base and the socket are marked with very fine radiating ridges and grooves, showing that the self-pruning habit of the tree is the result of a definite specialization of tissues and not a mere breaking or rotting away. In fact, the branch is usually still alive when it falls, and milk flows out of the tree into the exposed socket to cover the wound. The bark also soon grows over it and heals completely, leaving only a faint, rounded scar.

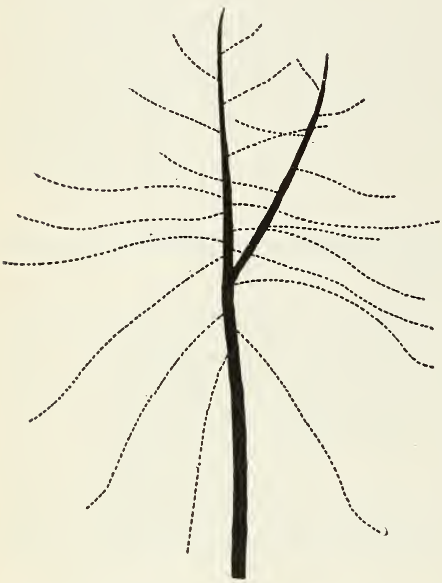


Fig. 4.—Diagram of a rubber tree with one permanent vegetative branch and numerous temporary fruiting branches.

The upright or permanent branches of Castilla are comparatively few in number. They arise, one in a place, at the right or the left of the base of a temporary branch, with the same regularity as in a stalk of cotton. They take a much more oblique or upright direction than the temporary or fruiting branches, which are usually nearly horizontal or somewhat drooping. The trees often grow to a height of 15 or 20 feet before any of the permanent branches develop, and then they often appear singly or a few at a time. (See fig. 4.)

The idea that extra-axillary buds are abnormal or exceptional appears to be quite as unwarranted in Castilla as in cotton. It would be possible for a Castilla tree to grow to seed-bearing maturity without producing any extra-axillary branches, but there would be formed in this way only a simple upright stalk or trunk. All of the branches that form the true permanent framework of the tree arise from extra-axillary buds that might be considered adventitious. Whether such buds are added after the formation of the internodes that bear them or are formed with the internodes and remain dormant at first is not certain. A permanent branch is often put forth at the base of a temporary branch that is still very young, in trees of sufficient age. That permanent branches of Castilla can arise as truly

adventitious buds is indicated by the fact that they often appear in considerable numbers along the edges of wounds, as when the bark is healing over gashes made in extracting rubber.

RELATION OF DIMORPHIC BRANCHES TO METHODS OF PROPAGATION.

There is no reason to suppose that the fruit-bearing branches of Castilla would take root, or that they could develop into normal trees. Sections of the trunk or of the permanent branches, on the other hand, take root readily, often when merely driven into the ground as fence stakes. In the Soconusco district of southern Mexico many instances were observed in which rubber trees were growing with apparent health and vigor from plantings as fence stakes. One of the largest rubber trees in the vicinity of Tapachula is said to have grown from a fence stake.[a]

The fact that the Central American rubber tree is capable of being propagated from cuttings is of practical interest in connection with the great differences in yields of rubber from individual trees. Though external conditions are undoubtedly responsible for some of the differences, there is every reason to believe that the characteristics of the individual trees will prove as important as among other cultivated plants. A system of vegetative propagation would enable such differences to be utilized directly, whereas an attempt to develop improved strains that would come true to seed might require many years of breeding. The utilization of the increased vigor and fertility of hybrids might also be made possible by a system of vegetative propagation.

The use of large cuttings in setting out new plantations would have cultural advantages in more quickly reestablishing the forest conditions that are now considered desirable in rubber plantations. Two of the systems of managing plantations that were quite popular at first have been found to have serious disadvantages. The leaving of the old forest to keep down the undergrowth by shade interfered also with the growth of the young rubber trees. Clean culture allows the trees to grow very rapidly at first, but their later development may be checked if the fertile surface soil is washed away and harmful grasses become established. The cleaning of the grassy plantations becomes more and more expensive, and also more and more harmful. The expected rate of growth of the trees is not maintained, and the period of profitable production of rubber recedes into an indefinite future.

Other difficulties in rubber culture come from the refusal of the latex to flow from the trees. Even when an encouraging yield is

[a] Cook, O. F. The Culture of the Central American Rubber Tree, Bulletin 49, Bureau of Plant Industry, U. S. Dept. of Agriculture, 1903, pl. 9.

obtained from first tappings, later attempts to secure latex from the vicinity of an old cut may be very disappointing. In the Para rubber tree (Hevea) there is a so-called "wound response" that results in continued and increased yields of latex from the paring back of the edges of the wounds, but in the Central American rubber (Castilla) the tapping of the bark in the vicinity of old cuts may bring out very little latex. The bark pressure that forces the latex out of new cuts is not restored around the old cuts. Only a small proportion of the latex is extracted by the present methods of tapping; the rest remains and dries up in the bark. If bark could be produced more rapidly by vegetative propagation, it might become practicable to harvest the bark as well as the latex and extract the rubber by mechanical means. Branches from the more productive trees would be available for extending the plantation.

THE PRUNING OF RUBBER TREES.

The fact that the rubber tree prunes itself so extensively leaves little work of this kind for the planter to do, but two precautions are not unworthy of consideration. The self-pruning mechanism does not always work successfully. If growth is very rapid the trunk may enlarge around the bases of the temporary branches and hold them in place, even after they are dead. This is also likely to happen when a branch has been injured or dwarfed, and thus lacks the weight necessary to break it away from its socket. Such decaying branches may give fungi or insects an entrance to the wood of the tree and thus induce decay. It would require very little additional labor to keep the plantation entirely clear of them. In most cases a pole with a simple hook or elbow at the end would enable them to be pulled out of their sockets, which would be better than cutting them off. The pruning away of some of the permanent branches may be desirable in the occasional instances where these come out too low down. The earlier these are removed the better, to keep the trunk of the tree smooth and erect for purposes of tapping.

DIMORPHIC BRANCHES OF COFFEE.

The upright branches or limbs of the coffee shrub are the equivalents of the original main stem; they bear no fruit, but can give rise to other uprights and to lateral branches. (See Pl. III.) The laterals bear flowers and fruit, and can also give rise to other branches of the same form and function, called secondary laterals, or simply secondaries, but no lateral branch ever produces a true upright branch. Unlike the cotton plant and the rubber tree, each internode of coffee bears two opposite leaves and is capable of producing two sets of branches, two axillary and two extra-axillary. In

rare cases an internode may bear three leaves and the branches may stand in whorls of three.

The buds that give rise to the upright limbs make their appearance in the normal position, in the axils of leaves, but the lateral branches develop in advance of the leaves of the joint to which they are attached, and appear to arise from near the bases of the joints or internodes of the uprights, instead of from the ends of the joints. (See Pl. IV.) They do not appear to have any connection with the leaf which is nearest them below. There is no difference of texture or line of separation between the upright and the young lateral branch. Both are covered from the first with the same continuous skin or epidermis, without groove or wrinkle. The lateral branches do not fall off or separate from the upright except by decay.

The lateral branches are always formed while the joint is young and growing, instead of pushing out afterwards, as do the adventitious or dormant buds. In this respect there is an abrupt difference between the primaries or first generation of laterals and the second generation or secondary laterals. These arise from the primary laterals at the axils of the leaves. Secondary laterals are seldom produced when the uprights are allowed to grow normally, but the growth of secondary laterals can be forced by severely pruning the uprights. Under unfavorable conditions, where the growth of the plants is alternately checked and forced, the formation of supernumerary secondary laterals represents a diseased condition, somewhat resembling the "witches'-brooms" of some of our northern trees. (See Pl. V.)

The axils of the lateral branches usually produce only flowers and fruits. The floral buds appear in large numbers clustered on several very short axillary branches. The secondary laterals can thus be understood as representing sterilized floral branches. Flowers are not normally formed on uprights. In the Bourbon coffee, which is abnormally prolific in flowers, the uprights are occasionally fertile to a slight extent.

PROPAGATION OF COFFEE FROM OLD WOOD OF UPRIGHT BRANCHES.

The prevalent idea that coffee can not be grown from cuttings has arisen, presumably, from attempts made with lateral or secondary branches (fig. 5). Pieces of the main stem or of upright branches take root readily and produce entirely normal trees. Several very successful examples of vegetative propagation of coffee from upright branches have been seen in Central America, though all were results of accidents, not of any definite intention to apply a new method. In such towns as Coban and Purula, in the coffee-growing districts of the mountains of eastern Guatemala, one often finds fence stakes of

old coffee wood putting out new shoots and forming new tops like vigorous young trees in a plantation.

Other cases were found in Costa Rica on the large coffee estate of Señor Don Federico Tinoco at Juan Viñas. Straight stakes cut from old coffee trees had been used to support the bushes in the rose garden of Señora Tinoco, and had promptly taken root. They had been allowed to grow, and had all developed into large, well-formed, productive coffee trees. Such instances certainly demonstrate the possibility of producing normal coffee trees by vegetative propagation. As there are considerable differences of soil and climate between Costa Rica and eastern Guatemala, it appears that such propagation is not narrowly limited to one set of conditions.

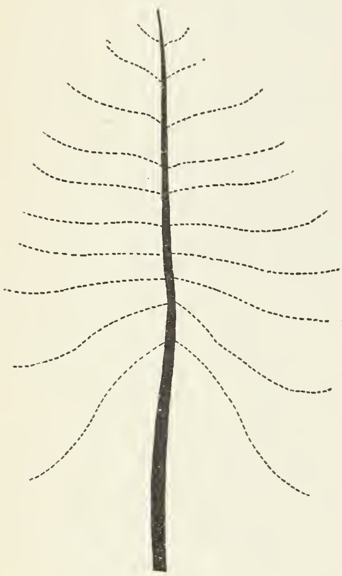


FIG. 5.—Diagram of a coffee tree with a simple trunk and numerous lateral fruiting branches.

If a system of vegetative propagation could be applied to coffee by the use of cuttings of the upright branches (fig. 6), several important cultural advantages might result. Much of the labor and expense now required for seed beds, nurseries, and transplanting would be saved, and plantations might be brought more rapidly to the size when good crops are produced and the ground is well shaded by the trees. The latter condition not only reduces the cost of cleaning the land of weeds, but protects it from injurious exposure and erosion.

The possibility of improving the coffee crop by the development of superior hybrid varieties also depends upon the use of some system of vegetative propagation, or upon the grafting of the young seedlings, as has been proposed in Java and other tropical countries. At present we have only the so-called Arabian type of coffee and the several mutative varieties which have been selected from it. Most of these, if not all, are inferior to the parent stock in fertility. Although very satisfactory in the matter of coming true to seed, they all seem to lack the first essential of an improved type, for they are generally less fertile than the parent stock.

In addition to the precaution of using the upright branches, other methods of treating the propagating stock will need, of course, to be worked out. It is quite possible that the cuttings can not be used in

a fresh condition, but may need some process of curing after they are cut, such as would allow new tissues to form on the cut surfaces before they are placed in the ground. In the successful cases of propagation from cuttings mentioned above, the wood had come from old trees that had been taken out of the plantations. Time may also have elapsed between the cutting of the stakes and the setting of them in the ground.

RELATION OF BRANCH DIMORPHISM TO THE PRUNING OF COFFEE.

The habits of growth and cultural requirements of coffee, and especially the principles of the art of pruning, can not be clearly understood without the recognition of the two kinds of branches. Planters who reason in a general way, without taking into account the dimorphism of the branches, often suppose that the pruning back of the uprights at the growing ends will cause them to send out new lateral fruiting branches lower down. This is a mistake, for new lateral branches are formed only on young, growing uprights, and then only two of the laterals from each joint of the upright.

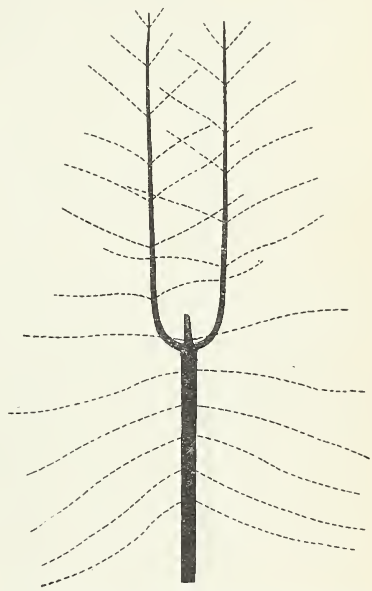


FIG. 6.—Diagram of a coffee tree with two upright branches and numerous lateral branches.

Additional development of lateral branches is to be obtained from mature uprights only by forcing the primary laterals to send out secondary laterals. If the primary laterals have been cut off no secondary laterals can be formed. Severe cutting back of the main trunks or upright branches is usual as a means of forcing more vegetative growth in the lateral branches. If the pruning is too slight it may have the effect of merely causing the primary laterals to elongate without forcing them to send out secondary lateral branches, for it is not a normal habit of the coffee tree to produce branches from the laterals. Left to itself without pruning, coffee usually produces only simple laterals and forms new lateral growth only through the medium of new uprights.

When all the axillary buds of the main stem have been eradicated no new uprights can be formed. If the tree continues to thrive, it spreads out on the ground as a tangled mass of slender decumbent

lateral branches. It is the custom of planters in Jamaica, according to Mr. G. N. Collins, of the Bureau of Plant Industry, to pull off the uprights instead of cutting them, on the ground that this prevents the growth of any more uprights. It is easy to understand that additional uprights may develop from buds of short basal joints of uprights that have been cut off, but this would not be the case with uprights that are pulled out. An additional bud can be seen on Plate IV, underneath the base of one of the new uprights that have been forced by pruning.

If the fertility of a plantation is to be maintained, resort must be had to some form of pruning, in order to continue the formation of healthy new wood on which good fruit can be borne. Old trees that are not pruned tend to produce slender branches, narrow leaves, and very small fruit. New wood can be obtained by allowing new uprights to develop or by preventing the growth of the uprights and forcing the laterals to branch. The use or the rejection of the uprights affords a fundamental distinction between the several different systems of pruning coffee.

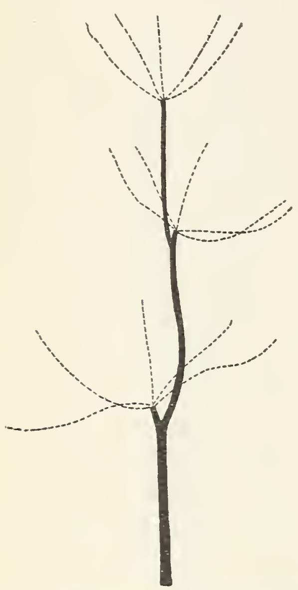


FIG 7.—Diagram of a cacao tree with three upright shoots and three groups of whorl branches.

The subject is one of too great extent and complexity to be discussed in detail here. Methods that may be thoroughly justifiable and advantageous under the conditions of one coffee-growing district may be objectionable in another, or even destructive, so greatly do the habits of the plants differ under different conditions of climate and soil. The practicability of the different systems of pruning depends also very largely upon the character and cost of labor. In some countries the natives show much aptitude for such work, but in others only the simplest systems can be applied: the cost of skilled assistance would be prohibitive.

DIMORPHIC BRANCHES OF CACAO.

The cacao tree bears two distinct kinds of branches, but these do not correspond directly to those of the rubber tree, the coffee, or the cotton. The fruit-bearing function is not confined to either type of branches. Both have vegetative functions, and both produce the small leafless twigs that bear the flowers and fruits. Even the main

trunk of the cacao tree produces flowers and fruit in the same way as the branches. In other words, cacao is cauliflorous.

The two kinds of vegetative branches can be distinguished readily by their position and also by the fact that they bear different kinds of leaves. The trunk elongates by a succession of upright shoots, each of which is terminated by a cluster or whorl of branches (fig. 7). (See Pl. VI.) The main stem and the upright branches have leaves with distinctly longer petioles than those of the lateral branches. The petioles of the leaves of the uprights are often 3 inches long, while those of the whorl leaves are less than an inch. (See Pl. VII, fig. 1.)

In the patashte tree (*Theobroma bicolor*), a relative of the cacao that is being introduced into cultivation in Guatemala, the specialization of the leaves of the two types of branches is carried still farther. The leaves of the main trunk and the upright limbs have petioles 8 or 10 inches in length, while the leaves of the secondary or lateral branches have petioles only about 1 inch long, as in the cacao. The blades of the two kinds of leaves of the patashte are also very different in size, shape, and texture, instead of being nearly alike as in the cacao.[a]

When a cacao seedling has grown a simple straight stem to a height of 2 to 4 feet, the single terminal bud gives place to a cluster or circle of three to six small buds, from which arises a whorl of as many branches. (See Pl. VI.) These branches soon diverge in a horizontal or oblique direction, but curve upward toward the end. In the petashte tree the number of branches in each whorl is always three, but in the cacao there are usually four, often five, and occasionally six. The whorled branches do not continue the upward growth of the main stem or trunk of the tree, but a new shoot for this purpose appears, in due time, on the side of the trunk, often an inch or more below the terminal whorl of branches. This lateral shoot curves upward and passes between two of the whorled branches into a vertical position, grows a few feet upward, and divides into another whorl of branches. Later on these upright sections seem to straighten more and more until the clusters of branches, which had previously terminated the trunk at its different stages of growth, are pushed over to the side, as though they were lateral clusters.

[a] The patashte tree also differs from the cacao in not being cauliflorous. The short inflorescence branches do not rise from the old wood of the main trunk and larger basal branches, but are confined to the axils of new leaves near the slender growing ends of the branches. The patashte is a much taller tree and grows much more rapidly than the cacao. It is usually from 12 to 20 feet high before it begins to branch, instead of branching within 3 or 4 feet of the ground, as the cacao usually does.

RELATION OF DIMORPHIC BRANCHES TO HABITS OF GROWTH.

Other cacao trees, both wild and cultivated, fail to show these habits of growth. Instead of the erect main stem, with branches in rosette-like clusters, the trunk divides near the ground into many oblique arms that form a broad spreading top of dense foliage, entirely unlike the open, irregularly distributed foliage of the trees with tall upright trunks. Planters of cacao have recognized cultural differences between the two forms of trees, the low, spreading type being preferable for plantation purposes to the tall type with the whorled branches.

It has been supposed that the different habits of growth betoken two different varieties of cacao, but seedlings from the spreading trees have not been found to show any tendency to reproduce the spreading habit of growth. If the spreading trees had any other character in common, the idea of a varietal difference might still appear to have some justification, but the fact is that both kinds of trees show the same general range of individual differences in the characters of the fruits, which are the only parts of the plant that lend themselves to careful comparison. The serious difference lies in the fertility, for the low, compact trees that shade their own short trunks and the ground underneath them appear to thrive much better in plantations than trees of the other type, and bear larger crops. In eastern Guatemala, where this matter was studied in some detail, it was the opinion of a very intelligent cacao planter, Don Ricardo Fickert-Forst, owner of the Trece Aguas estate, that the low, spreading trees would bear, on the average, at least twice as much cacao as the others, and that they would continue to be fruitful for a longer period of years. Efforts had been made to obtain more of the spreading trees by planting seeds from trees of this form.

The failure of such attempts can be explained after the serious differences between the two kinds of branches are recognized. The low, spreading trees have this desirable form because they do not produce any of the upright shoots and whorls of branches. Their method of branching is the same as that shown on whorl branches, that are incapable of forming uprights, as already explained. Although there is no indication of a whorled arrangement of the main branches of the spreading trees, it may nevertheless be considered that the tops of these trees represent the development of only one or two of the branches of an original whorl, and this would afford an adequate explanation of the formation of a different type of tree.

The inability of the whorled branches to produce any upright shoots would explain why a tree top formed from such a branch would not have any of the strong upright shoots, but would produce

only the relatively slender oblique or lateral shoots proper to the branches that are formed as members of a whorl. If only one or two of the branches of the first whorl were to survive and to begin branching near the base, the further growth of the tree might come from the development of these whorled branches, the upright type of the branches falling into complete abeyance. The question of being able to produce at will the desired type of tree appears to turn on the treatment of the young tree at the time it puts out the first or second whorl of branches.

RELATION OF DIMORPHIC BRANCHES TO THE PRUNING OF CACAO.

Recognition of the dimorphism of the branches of the tree is a matter of even more fundamental cultural importance with cacao than with coffee, since it enables us to understand differences in habits of growth that determine the productiveness and even the life of the trees. Much of the advice regarding the pruning of cacao has been given without regard to the dimorphism of the branches, and is misleading, if not actually dangerous. Some writers have recommended the removal of some of the branches of the lowest whorl if the tree begins to branch too low down, and others have held that only three or four of the whorl branches should be allowed to develop when five or six are produced. In neither case has it been considered that the preliminary treatment might have the effect of a complete alteration of the habits of growth of the tree.

If the production of whorled branches is to be allowed to continue so as to produce trees of the upright, open form, it is very doubtful whether any advantage can be gained by removing a few of the branches of a whorl. The effect is to weaken the basal ring of wood that supports the whorl in its rather precarious position at the end of the long, upright shoot. When the strength of this ring is diminished the weight of the branches is likely to split them apart. Moreover, the wood of the cacao tree is so soft that decay is very likely to follow any injury—another reason why any attempts at pruning should be confined to the very youngest stages of the growth of the branches.

If an attempt is to be made to compel the young tree to form its crown from one or two of the whorl branches, it is also very important that these keep the more nearly upright position that they have in their early stages. If pruning be delayed until the whorl has opened out and the branches have become nearly horizontal, the chances of having a well-shaped crown are very small. It may also be desirable not to let the branches that are left grow too long. Pinching off the end when they are about a foot long would force

them to send out secondary or lateral branches near the base and thus assist in forming a compact, well-shaped crown. With two or more strong branches from near the base of a single whorl branch a condition somewhat similar to the original whorl may develop, but essentially different in the subsequent habits of growth, since these branches do not tend to spread apart like true whorl branches, and are able to continue the upward growth of the tree without the formation of any more upright shoots from the main trunk.

A further indication that the habit of forming the whorled branches represents a definite specialization may be found in the fact that the upper leaves of an upright are often aborted. The stipules are of the normal size, but the petioles and blades do not develop. The stipules soon drop off, leaving small scars on the surface of the bark as the only indication of the joints.

It is not clear whether this habit of forming abortive leaves is to be viewed as an adaptation to avoid the clustering of too many leaves at the top of an upright shoot, or is connected with the shortening of the internodes to form the whorl of branches. When the leaves are aborted many short internodes are likely to be formed below the whorl. In other cases there are no abortive leaves. Even the whorled branches may arise from axils of normal, full-sized leaves, but in such cases the whorl is likely to be somewhat irregular, as though the internodes had not been sufficiently shortened.

If these reduced leaves are taken into account, the cacao tree may be said to have three kinds of leaves, the leaves with the long petioles on the lower parts of the uprights, aborted leaves at the ends of the uprights, and short-petioled leaves on the whorled branches. The specialization of the leaves of the cacao is somewhat similar to that of the pine tree. Young seedlings and new shoots of pines that have been cut down or severely pruned have functional green leaves all along the shoot. Ordinary shoots and branches of pine trees have no functional green leaves, but only scalelike membranous sheathing leaf bases. The functional leaves of adult pine trees represent the terminal clusters of a few leaves at the ends of very short specialized branches that appear to be incapable of further growth. New branches have to be developed from special zones where the axillary buds of the leaves of the uprights remain dormant instead of producing the short leaf-bearing branches.

The habit of the cacao tree to produce the long uprights with a whorl of branches at the end appears thoroughly undesirable from the cultural standpoint, but if we consider the habit of the wild cacao to grow in dense thickets with many other kinds of woody vegetation its peculiar habit of growth may be seen to have some advantages. The rapid growth of the upright shoots enables a cacao tree to raise

a terminal whorl of branches above the surrounding vegetation, and thus secure an amount of exposure to sunlight that might not be obtainable otherwise. Though the cacao must be reckoned as one of the shade types of vegetation it does require light. The most vigorous and productive cacao trees are those that stand out in full exposure to the light, but the soil conditions must be very favorable to enable the trees to thrive with full exposure.

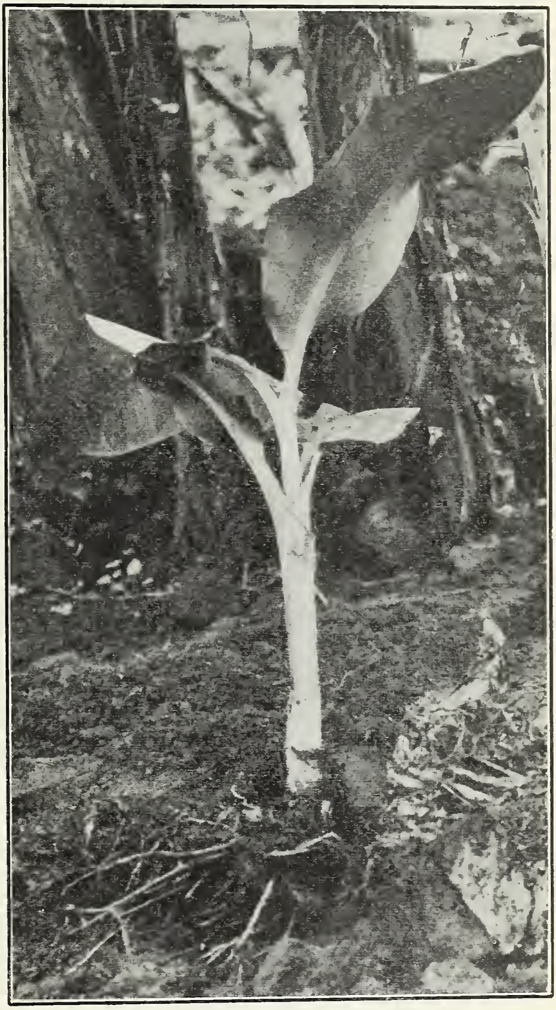


Fig. 8.—A broad-leaved sucker of a banana plant from Costa Rica. (Greatly reduced.)

DIMORPHIC BRANCHES OF THE BANANA PLANT.

Although the habits of growth of the banana plant are altogether different from those of the shrubby and woody species previously described, there is a definite dimorphism of branches that has to be taken into account in studying the habits of growth and the problems of cultivation. Banana planters regularly distinguish between "sword suckers" and "broad-leaved suckers," but the nature and the extent of the differences between the two kinds of offshoots have not been adequately appreciated. The effects of external conditions have been supposed to explain the differences, although both kinds of branches are almost always to be found on any well-developed plant.

The names of the two kinds of offshoots allude to differences in the size and shape of the leaves. The broad-leaved suckers begin near the ground to produce leaf blades of the same general form as those of the adult plant (fig. 8). The sword suckers produce at first only small narrow blades that by their shape suggest the name (fig. 9). The basal, sheathing parts of the leaves that form the so-called "trunk" of the banana plant are much larger in the sword suckers, and this renders the reduction of the blade of the leaf a more evident specialization.

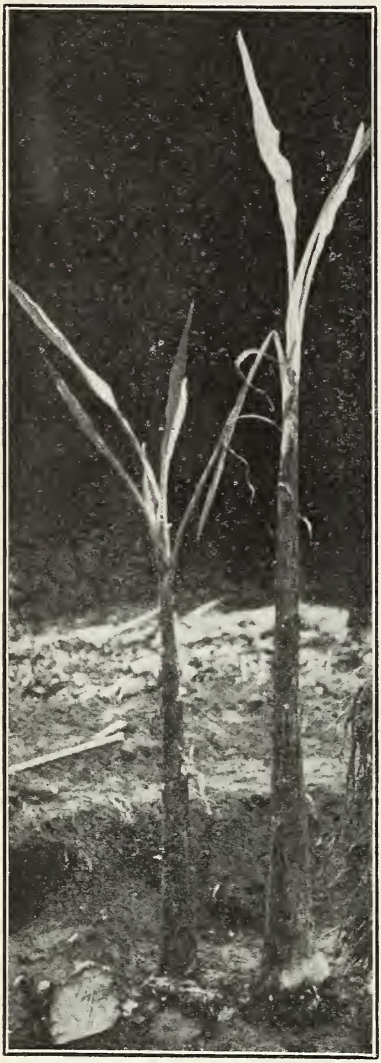


Fig. 9.—Sword suckers of the commercial banana, used in setting out plantations in Costa Rica. (Greatly reduced.)

Possibly the dimorphism of the branches is not as definite in the banana as in the woody plants previously considered. Though no connecting stages between the two kinds of branches were noticed in the rootstocks that were dug out and examined, it may be that intermediate conditions will be found occasionally, as in Indian corn. The intermediate joints of corn plants, between the ears and the suckers, seldom develop branches, but when such branches are developed they are intermediate in form, as well as in position.

The differences in the development of the leaves call attention at once to the fact that the two kinds of banana suckers stand in different relations to the parent plant. The broad-leaved suckers, with their relatively large, expanded leaves, are able from the first to elaborate a larger part of the nourishment they require than are the sword suckers, yet in spite of this apparent advantage the broad-leaved suckers are of much slower growth. It is evident from this fact that the sword suckers stand in a different relation to

the parent plant and draw a much larger proportion of nourishment from it.

These differences of relation are made still more obvious when it is learned how the two kinds of branches originate. The broad-leaved suckers come from buds around the sides of the rootstocks, near the surface of the ground. The sword suckers begin their development deep in the ground, underneath the parent rootstock. They have at first the form of slender, subterranean shoots, that grow first in a horizontal direction or even obliquely downward. They thicken into a large fleshy bulb before beginning to grow much above ground. (See Pl. VII, fig. 2.)

The sword suckers may be looked upon as true permanent branches of the parent rootstock, while the broad-leaved suckers are better adapted for separate propagation under natural conditions. Many of the latter are put out above the surface of the ground. Some of them have at first the form of small, rounded tubers, the buds remaining entirely dormant. A banana plant that has been uprooted by the wind does not die at once, but puts out from about its base a large number of these potato-like tubers, which finally fall off and are readily scattered, or roll down hill. The wild relatives of the banana plant are natives of steep, rocky hillsides, where such a method of vegetative propagation would be distinctly advantageous.

CULTURAL VALUE OF TWO TYPES OF OFFSHOOTS.

Banana planters generally follow the rule of using the sword suckers in setting out plantations, on the ground that they produce fruiting plants quicker than the broad-leaved suckers. This is easy to believe, in view of the larger amount of stored nourishment that is carried over to the new plants by using the much thicker bulb of the sword suckers instead of the relatively small rootstocks of the broad-leaved suckers. Some planters in Costa Rica doubt whether the broad-leaved suckers ever produce fruit of their own, and are inclined to believe that fruiting does not begin until the necessary sword suckers have had time to grow. In Jamaica, on the other hand, the sword suckers are cut back nearly to the ground before planting and the first crop comes from the growth of new suckers.[a]

[a] See Stockdale, F. A., "The Question of a Banana Industry," Journal of the Board of Agriculture of British Guiana, vol. 3, no. 2, 1909, p. 79.

"The suckers which would be selected for planting [in Jamaica] are not the same as those that would be chosen in this colony [British Guiana], and the method of treatment is totally different. Suckers for planting purposes are suckers that have not been cut back, or in other words, 'sword suckers'—as indicated by their first leaves being very narrow—which have been allowed

The use of the most vigorous suckers appears especially important, not only to obtain the earliest possible crop from a new plantation, but because it is also highly desirable for a new plantation to grow up rapidly and shade the ground as soon as possible, thus protecting itself from harmful weeds and lessening the cost of cultivation. The later welfare of the plantation may also be affected by its early prosperity. The shading of the ground not only helps to maintain favorable soil conditions and thus conduces to larger crops, but larger numbers of the quick-growing sword suckers are produced in prosperous, shady plantations. The exposure of the base of a banana plant to much light appears to stimulate the formation of broad-leaved suckers, as though the plants had the intention to occupy the surrounding land before turning their attention to the production of fruit.

THE PLANTING OF RESTING TUBERS.

Although the production of many broad-leaved suckers may be considered to represent an unfavorable condition in a plantation, they are not without interest and utility from other points of view. The much greater abundance in which the broad-leaved suckers are produced would render them of very distinct importance in any attempt to propagate a new variety or special strain derived from a single superior plant. A rootstock can not be expected to produce more than three or four sword suckers at one time, while a score, or perhaps several scores, of broad-leaved shoots might be obtained if a plant were treated with this end in view. Study might well be given to the finding of differences in habits of branching. A strain that would produce only a few suckers would be more valuable in the plantation, for the pruning away of superfluous suckers is one of the chief items of expense in many banana plantations. Such a strain might be at a disadvantage, however, in furnishing stocks for new

to grow to about 8 or 10 feet in height and which have large bulbs at their base. No small suckers, such as we choose in this colony, are taken. In preparing their suckers for planting the Jamaicans cut down those selected to within about 6 inches of the ground and then dig out the bulbs. All the old roots are then trimmed off, and the bulb is planted so that the eyes are at least 3 or 4 inches below the level of the ground. From this bulb three or four suckers will spring up. The strongest one is selected, and all the others are pruned off until June, when one or two suckers are left, and then, again, all others are pruned off until October, when there is again left either one or two, and finally another is left the following February. It is calculated that the first suckers should fruit in the following March, the June suckers in May, the October ones in February or March, twelve months, and the February one in May or June, twelve months. This system for timing is the outcome of long experience and could not be adopted in this colony without modification on account of differences in climatic and rainfall conditions."

plantations, unless it could be made to yield more numerous offshoots when these were required.

The use of the hardened resting tubers may be considered as the ideal condition for shipping propagating stock of the banana from one country to another. The question of diversifying the American banana industry by the importation of some of the superior types of banana of the Old World has often been raised. One of the difficulties has been to obtain new stocks in sufficient quantity, even for adequate experiments to be made. This has appeared to stand in the way of any immediate practical results being obtained, and has undoubtedly tended to discourage attempts to obtain superior varieties.

It is also possible that the broad-leaved suckers may be found useful in dealing with some of the banana diseases that appear to indicate a weakening of the vitality of some of the best strains of the commercial banana, as in the case of some of the superior varieties of sugar cane. The sugar planters of Java bring down new stock from the mountains, because the mountain-grown canes have been found more resistant to disease than the same variety grown continuously in the lowland plantations.

The tuber-like, broad-leaved suckers that are formed on uprooted banana plants may be looked upon as a resting state, and may be expected to have a relation to subsequent vigor of growth. An interruption of growth might be directly beneficial, or if different conditions prove to be necessary, as in the case of the sugar cane, the tubers would greatly facilitate the exchange of propagating material. They could be collected and transported from one district to another much more readily and cheaply than the large, heavy sword suckers.

As a means of testing the possible effect of the resting stage upon the subsequent behavior of the plants, a suggestion was made in 1903 to Prof. H. Pittier, who soon after took charge of the experimental plantations of the United Fruit Company in Costa Rica, that plantings be made of these potato-like tubers to see whether any differences of behavior would be shown. In 1904 a hectare (about 2½ acres) of land was planted with these small resting tubers, instead of the usual sword suckers. The growth of the plants was unexpectedly rapid and did not fall behind that of the neighboring fields that were planted with large sword suckers. The first crop was matured in about nine months, the usual time under the Costa Rican conditions, and with more than usual uniformity, each plant producing a large, well-formed cluster of fruit. It was also noticed that the plants of this field produced very few suckers around the base until after fruiting, in very distinct contrast with adjoining fields planted with the sword suckers. When Professor Pittier made a visit to Costa Rica in 1907, three years after the beginning of the

experiment, this field still appeared very distinctly superior to any of the adjoining areas.

Although no observations or tests were made to determine the resistance of these plants to disease, it is apparent even from this single experiment that commercial crops of bananas can be produced under conditions that would give a considerable measure of protection against disease. The resting tubers would be much less likely to convey diseases than the sword suckers, and could be much more easily disinfected. Some of the banana diseases that become very serious in old plantations appear to have little or no effect upon vigorous young plantations under favorable conditions. The more frequent replanting of bananas, every two or three years, is being advocated among the Jamaica planters, because the old stocks are thought to " run out " and become less vigorous, and also because the young plants can be brought into fruit with greater regularity.[a]

The possibility of producing a full and regular crop of large clusters of fruit by the use of tubers instead of sword suckers would also make it more feasible to use bananas in a rotation of crops, a policy which may prove to be as desirable in tropical cultures as in those of temperate regions, if a permanent use of the land is to be maintained. If the destructive policy of raising bananas for a few years and then abandoning the land continues to be followed in Central America, it will probably not require many decades to exhaust all the districts that are well suited to banana culture and at the same time readily accessible from the United States. In a few favored spots where soil conditions are ideal or where new soil continues to be deposited by floods of adjacent rivers, permanent cultures may be maintained, but in most places the prosperity of a banana plantation appears to have definite natural limits.

COMPARISONS OF DIFFERENT SYSTEMS AND TYPES OF BRANCHES.

One reason why dimorphism of branches has not received more attention is doubtless to be found in the fact that current botanical classifications of buds and branches do not provide adequate recognition for the different kinds of diversity shown by the branches, as among these tropical crop plants. The view generally stated or implied in text-books is that branches are to be divided, with reference to their methods of origin, into two principal kinds, axillary

[a] "There is a growing tendency throughout the whole island to reduce the period of ratooning and to replant every two or three years, as it is found that by so doing the crops may be better timed for the American market, as after first ratoons the plants fruit somewhat irregularly." (See Stockdale, F. A., "The Question of a Banana Industry," Journal of the Board of Agriculture of British Guiana, vol. 3, no. 2, 1909, p. 81.)

and adventitious. This compels us to infer that branches which do not come from the axils of the leaves must be regarded as adventitious, or to some extent irregular and abnormal.

It may be that the present series of facts of dimorphism will incline botanists as well as planters to take into account the normal and regular existence of branches which are neither truly axillary nor truly adventitious. It is as impossible to understand the habits of growth of the plants from the botanical standpoint as it is to find correct principles of cultivation and pruning without seeing that the same plant can produce two or more kinds of branch organs essentially distinct from each other in position, form, and function.

The different systems of branching have evidently been specialized on independent lines that could hardly be described on the basis of the usual classification of branches into two general classes—axillary and adventitious. There should be no implication that extra-axillary buds are of necessity adventitious, or that extra-axillary or adventitious buds are less important in any particular plant than axillary buds. There are no general relations between the position and the function, nor between the position and the time of appearance, nor yet between the time of appearance and the function. There are no general principles that apply to the dimorphic branches of all the different plants, nor do any two of them fully agree.

The extra-axillary branches of the coffee have the fruit-bearing functions of the axillary branches of Castilla, while the axillary uprights of coffee correspond functionally to extra-axillary uprights of Castilla. The axillary branches of Castilla must be considered as more definitely limited on the vegetative side than the extra-axillary branches of the other plants, in view of their temporary nature.

The specializations shown in the branches of the cotton plant are in some respects quite the opposite of those of the Central American rubber tree. The flowers and fruit of the cotton plant are borne on extra-axillary branches, those of Castilla on the axillary branches. The vegetative limbs of Castilla are all extra-axillary, while those of cotton are axillary. The axillary or fertile branches of Castilla are temporary, while the extra-axillary serve as permanent divisions of the main stem.

Coffee agrees better with cotton than with Castilla, since it is the axillary buds which give rise to the permanent, upright shoots. The extra-axillary branches of cotton and coffee are also alike in the bearing of fruit. Though extra-axillary in position they can hardly be called adventitious. Indeed, they are less adventitious than the axillary branches, for they are developed with far greater regularity. Extra-axillary buds in cotton and coffee seem to lack the power of remaining

dormant. They do not appear to be present on young plants, and they are never added after the internode and its leaf or leaves have become mature. They are laid down with regularity as a part of each internode of the adult plant.

The extra-axillary buds, both in cotton and coffee, are developed with the same invariable regularity as the leaves themselves. They resemble adventitious buds only in the technical sense that their position is extra-axillary. Considered from the standpoint of the habit and functions of the plant, they are not more adventitious than the terminal or the axillary buds.

Before the young internode emerges from between the stipules of the coffee leaves, the three buds that give rise to the central axis and the two lateral branches can be found standing in a row with the axillary buds and only very slightly above them. Later on the three buds are pushed out nearly together, but the middle one soon leaves the other two behind. Strictly speaking, therefore, the extra-axillary branches of coffee arise from subterminal buds. After the branches are formed there is no internal indication of a joint or septum; the pith is quite continuous. Thus an internode of a main stem or an upright branch of coffee does not appear to be a simple cylinder, but a three-armed fork or trident.

The lateral branches of the coffee plant do not normally branch again, though they can be forced to do so by pruning. The secondary lateral branches are produced from sterilized flower buds, and have only the characters of laterals, never of uprights. Persistent pruning may exhaust all the buds capable of forming uprights and leave the tree a tangle of horizontal or drooping branches, apparently without the power to put forth any more uprights.

Branches of definitely limited possibilities of vegetative growth, like the fruiting branches of coffee and Castilla, may be considered as having intermediate functions between those of leaves and of ordinary types of vegetative branches. The leaves of Begonia and Bryophyllum, which produce plantlets from adventitious buds, and the leaf-like flower-bearing organs of Phyllanthus and Phyllonoma represent other intermediate stages between ordinary leaves and branches. The leaf-like branch organs of some of the relatives of asparagus, such as Ruscus and Semele, might be mentioned in the same connection. Even the tobacco leaf may develop a row of vegetative buds along the base of the midrib. The axillary branches of Castilla are as definitely deciduous as the leaves. The permanent branches of coffee are formed from axillary buds, while those of Castilla appear to be adventitious as regards the time of development, though they have definite positions.

Unless the different branch organs are to receive distinctive names in each of the different plants, it will be necessary to content our-

selves with a few general terms that will enable us to indicate more directly the nature of these various kinds of branches. A primary distinction can be made as to whether a bud is laid down when the branch grows or is formed afterwards from unspecialized tissues of the bark. Buds that are not adventitious in the latter sense, but are formed with the growth of the internode to which they belong, might be called natal buds.

Adventitious branches are not supposed to have regularity of position, but such regularity should not be allowed to obscure their adventitious character if they are formed subsequent to the growth of the internode. The loss of the original axillary bud may be followed by the development of an adventitious axillary bud, as happens in coffee. Also the flower buds of coffee appear to be adventitious to a very considerable extent, and perhaps altogether so. With severe pruning, leafy branches may also be forced from the axils of the leaves of the fruiting branches long after the normal production of flowers and fruits would have ceased. This may be taken to show either that additional adventitious buds can be formed in the axils after the fruiting period is past, or that the axillary buds of the fruiting branches have previously remained dormant and not taken part in the production of flowers and fruit.

The fact that flower buds can be adventitious only emphasizes the more the absence of any general connection between origins, positions, and functions, for plants have always had flowers, or at least the essential sexual organs, even before they had the present specializations of their vegetative parts into branches and leaves. Flower buds could never be considered adventitious if we were to attach any functional sense to the term, but they appear adventitious with respect to the time and method of origin on the individual plant.

The terms axillary and extra-axillary are sufficient, perhaps, for the designation of the positions of the two kinds of buds on any particular plant, but as a general term extra-axillary is extremely indefinite. It groups together buds arising from internodes of the stem or trunk and those coming from the roots, as in the plum, pear, breadfruit, and sweet potato. It does not distinguish between the conditions to be found in coffee, where the extra-axillary branch is far above the axil, and in cotton and Castilla, where the extra-axillary branch is at the side of the axil.

Some might prefer to describe the cotton plant or the coffee tree as having two axillary buds, and thus avoid the tendency to confuse extra-axillary position with adventitious origin, but it is evident that no scientific object can be gained by applying the same name to things as different as the two kinds of branches. In the strictly mathe-

matical sense only one bud could be axillary. No subsequent adventitious bud could be truly axillary. Yet to apply such a distinction to coffee would reduce it almost to an absurdity. Some of the fruit buds might be reckoned as axillary, but others closely adjacent would have to be considered as extra-axillary. The leafy branches which can be forced from these same axils by pruning would be axillary if they came out first, or extra-axillary if they followed a crop of flowers, a purely artificial distinction. Instead of attempting to establish too sharp a contrast between axillary and extra-axillary it would be better to admit a third and intermediate positional category of adaxillary branches, for those that stand close to the axil, as distinguished from extra-axillary branches that are distinctly separated from the axil.

If many buds arise simultaneously or successively from the axillary position, or as near to it as they can be placed, they might be termed coaxillary. The inflorescence branches of coffee could be described as coaxillary, and probably those of Cuscuta.[a]

In describing the functions of branches, distinctions are also to be observed. Some branches are completely vegetative and produce no flowers or inflorescences; some are completely reproductive, in the sense that they bear only floral buds. Between the two extremes a great multiplicity of intervening stages exists. Sometimes branches which normally bear fruit can be sterilized and rendered purely vegetative. In some plants all branches have equal vegetative potentialities; in others, as in coffee, cotton, and Castilla, the upright main stems are different from the lateral fruiting branches. In some plants these lateral branches can, in case of accident, become substitutes for upright stems; in others, they can furnish buds from which upright stems can arise; in still others, the lateral branches are without the power to replace the main steam.

The existence of two or more buds in or about the axil of a leaf is known, of course, in many plants and has been recognized by writers on plant morphology, but definite specializations of positions and functions have not received the attention required by the agricultural importance of such facts. As long as no difference of function has to be considered, additional buds can be considered as mere substitutes or accessories of the true axillary bud. Thus Pax[b] recognizes what

[a] Dr. C. E. Bessey, in a paper on the adventitious inflorescence of *Cuscuta glomerata*, stated that the examination of young plants shows that the inflorescence is developed from numerous crowded adventitious buds and not by the repeated branching of axillary flowering branches, as commonly stated. Science, vol. 4, 1884, p. 342.

[b] Pax, F. Allgemeine Morphologie des Pflanzen, p. 16.

he calls "beisprossen," or accessory shoots, and subdivides these into two classes: (1) Serial shoots, if they arise one above the other, and (2) collateral shoots, if they appear side by side.

Until more general studies and classifications of methods of branching can be made it seems best to retain the ordinary designations of uprights, laterals, etc., especially in connection with plants to which these terms have already been applied. All that can be attempted at present is to indicate the varied relations between the different positions and functions of branches in the plants that have been studied.

SUMMARY OF TYPES OF BRANCHES.

The characters of the different kinds of branch individuals of cotton and the other plants with which it has been compared can be defined or briefly described as follows.

BRANCHES OF COTTON.

(1) *Axillary limbs.*—Natal axillary branches which never produce flowers, but are like the main axis of the plant in forming at each node an axillary vegetative bud and an adaxillary bud that may give rise to a vegetative or a fertile branch.

(2) *Fertile branches.*—Natal adaxillary branches which produce a flower bud on each internode, in an adaxillary position, and an axillary vegetative bud.

(2a) *Vegetative branches.*—Natal adaxillary branches which have the same form and functions as the main stem or the axillary limbs.

In varieties that have normally complete dimorphism of the branches, axillary buds give rise to vegetative branches only. Adaxillary buds can produce fertile branches or vegetative branches, except on fertile branches, where they produce flowers.

The cotton flower is always solitary, except in cases of fasciation, that are rather common in cluster varieties. Being extra-axillary, the flower is not directly subtended by a leaf or a bract, though there is a whorl of three bract leaves at the end of the simple peduncle.

BRANCHES OF CASTILLA.

(1) *Temporary branches.*—Natal axillary branches producing leaves and inflorescences; short lived and deciduous; not able to serve as main stems.

(2) *Permanent branches.*—Adventitious adaxillary or extra-axillary branches, bearing leaves and temporary branches, but no inflorescence branches; serving as permanent divisions of the main stem.

(3) *Inflorescence branches.*—Natal coaxillary branches borne on the temporary branches in clusters of four male inflorescences or two male and one female.

BRANCHES OF COFFEE.

(1) *Upright branches.*—Natal axillary branches not producing inflorescence branches; serving as equivalents of the main stem.

(2) *Lateral branches.*—Natal extra-axillary branches attached to the bases of the internodes of the main stem or of the upright branches. Lateral branches produce leaves, inflorescence branches, and secondary laterals, but are unable to replace the main stem.

(2a) *Secondary lateral branches.*—Adventitious branches arising from axillary buds of the lateral branches. They are inflorescence branches pushed into vegetative growth by severe pruning. In form and function they agree with the lateral branches.

(3) *Inflorescence branches.*—Natal and adventitious coaxillary branches borne in clusters on lateral and secondary lateral branches.

BRANCHES OF CACAO.

(1) *Upright branches.*—Probably adventitious extra-axillary branches, bearing long-petioled leaves and able to produce branches of all three kinds and to become permanent parts of the main stem.

(2) *Whorled branches.*—Natal axillary branches produced in whorls and terminating upright branches. Whorl branches bear short-petioled leaves, lateral branches, and inflorescence branches, but are unable to replace the main stem.

(2a) *Lateral branches.*—Natal axillary branches produced by whorled branches and having the same functions; not producing whorled branches or main stems.

(3) *Inflorescence branches.*—Adventitious extra-axillary branches arising from the mature wood of the main trunk and the whorled and lateral branches, without power to replace the main stem or the vegetative branches.

BRANCHES OF THE BANANA PLANT.

(1) *Sword suckers.*—True branches of the rhizome that arise from subterranean buds, develop large bulbous bases, and put forth narrow leaves when young.

(2) *Broad-leaved suckers.*—Offshoots adapted for separate vegetative propagation, arising from superficial buds and bearing broad-bladed leaves while still young.

The relations between the positions and the functions of the branches of the four woody plants are summarized as follows:

Summary of the classification of branches.

Description.	Cotton.			Castilla.		Coffee.			Cacao.	
	1.	2.	2a.	1.	2.	1.	2.	2a.	1.	2.
Origin:										
Natal buds	×	×	×	×	......	×	×	......	......	×
Adventitious buds	......	......	......	......	×	......	......	×	×	......
Position:										
Axillary	×	......	......	×	......	×	......	×	......	×
Adaxillary	......	×	×	......	×	......	......	......	......	......
Extra-axillary	......	......	......	......	×	......	×	......	×	......
Reproductive function:										
Fertile	......	×	......	×	......	......	×	×	×	×
Sterile	×	......	×	......	×	×	......	......	......	......
Vegetative function:										
Able to form main stems	×	......	×	......	×	×	......	......	×	......
Not able to form main stems	......	×	......	×	......	......	×	×	......	×

CONCLUSIONS.

Definite dimorphism of branches exists in at least five important tropical crop plants—cotton, coffee, cacao, the Central American rubber tree (Castilla), and the banana. Each normal plant produces two kinds of branches, with regular differences of form and function.

The factor of branch dimorphism must be taken into account in the scientific study of the structure and habits of all these plants, as well as in the breeding and adaptation of varieties. Systems of cultivation and pruning must likewise be planned with reference to the habits of branching.

In each species there is a definite relation between the functions of the branches and their positions or places of origin on the internodes, but there is no general relation of position to function that applies to all the species, or even to any two of them. It is necessary to consider each plant separately in order to understand the agricultural importance of the dimorphism of the branches.

In the cotton plant the branches that arise in the axillary position have vegetative functions only, like the main stalk. The branches that produce the flowers and fruit are extra-axillary; that is, they arise at one side of the axillary branch or bud. Branches with the vegetative form and functions may replace the fruiting branches, in the extra-axillary position, but no normal fruiting branches develop in the axillary position.

The definite differentiation of the two kinds of branches represents a normal condition in all the types of cotton that have been studied

from this point of view. Intermediate forms of branches are accompanied by abortion of flower buds and other abnormalities.

The substitution of additional branches of the vegetative form for the fruiting branches is a frequent occurrence in imported types of cotton. The plants regain their normal fertility when the normal relations of the branches are restored. This readjustment of the habits of branching represents one phase of the process of acclimatization.

The dimorphism of the branches is also a factor in the problem of weevil resistance, since the development of larger or more numerous vegetative branches tends to render the crop late. Early crops usually suffer less injury from the weevils.

In the Central American rubber tree (Castilla) the axillary branches do not share all the functions of the main stalk or trunk of the tree. The axillary branches bear the flowers and fruit, but are shed after a few seasons. The permanent branches always arise from extra-axillary positions and usually do not begin to develop until the tree is several years old.

The self-pruning habit of the Central American rubber tree is an important cultural advantage. Only an occasional tree requires pruning, and then only to correct accidents or abnormalities.

In the coffee tree only vegetative branches, or uprights, like the primary trunk, are produced from the true axillary buds. All the fertile branches, or laterals, have extra-axillary positions above the true axillary branches. Lateral branches can not produce uprights, nor can new laterals be produced from old uprights.

As the crop is borne only on young wood of lateral branches, a vigorous growth of lateral branches must be maintained if good crops are to be secured. New uprights must be formed to produce new laterals, or laterals may continue to grow and subdivide if the growth of uprights is prevented by pruning. Failure to take the dimorphism of the branches fully into account in the work of pruning often results in serious injury to coffee plantations. The practical value of the different systems of pruning the coffee tree depends on local conditions of climate and soil, as well as upon the quality and cost of the labor supply.

In the cacao tree fruit twigs may be borne on all parts of the old wood, including that of the main trunk, but there are two types of vegetative branches. The upright growth of the trunk takes place by a series of shoots, each of which is terminated by a whorl of three to six branches. A new upright shoot arises from the side of another upright, not from a whorl branch.

The natural habit of growth of the cacao tree, by a succession of whorls, is very undesirable in plantations, and can be avoided by

judicious pruning of the young trees to induce them to develop their crowns from some of the members of the first whorl of branches, instead of allowing them to produce a succession of uprights and whorls.

The banana plant also produces two forms of suckers or offshoots, corresponding to the dimorphic branches of the woody species. The so-called sword suckers represent true permanent branches of the rhizome. They arise from large subterranean shoots nourished by the parent plant, and bear at first only narrow, sword-shaped leaves.

The so-called broad-leaved suckers arise as relatively small shoots from near the surface of the ground. Even in the young stage they produce broad-bladed leaves like those of the adult plant, and are adapted for separate propagation.

Dormant tuber-like suckers of the broad-leaved type are formed on uprooted rhizomes, and constitute a readily portable form of propagating stock from which vigorous and productive banana plants may be grown. The use of such tubers may render it possible to produce bananas under a system of rotation with other tropical crops.

198

PLATES.

198

59

DESCRIPTION OF PLATES.

Plate I. Abnormal branches and involucres in the Dale variety of Egyptian cotton, where such abnormalities are especially common, though they occur also in other Egyptian varieties, as well as in Upland cotton. The figure near the upper left-hand corner of the plate represents a normal involucre of Egyptian cotton seen from the side, so that only one of the three bracts is shown. The figure at the top of the plate and that with the largest leaf immediately below represent the first stages of transformation from leaves to bracts, with the stipules enlarged, the petiole shortened, and the blade reduced in size, but retaining the texture of a normal leaf. Other figures show intermediate conditions, with the petiole suppressed, the blade more reduced and united with the stipules, and the texture becoming the same as in an ordinary involucral bract. The lower right-hand figure shows an involucre with only two bracts, the upper bract still of the intermediate form, while the lower is nearly normal, except at the base, where there is an unusually large bractlet. (Natural size.)

Plate II. Bolls produced on short axillary branches of the Dale variety of Egyptian cotton. The long stalks of these bolls represent the fused joints of rudimentary branches, as shown by the presence of small bractlike leaves and stipules. In the figure on the left-hand side of the plate there is a bractlike organ in the position that would be occupied by a leaf on a normal fruiting branch. In the figure at the bottom of the page this organ is reduced to the size of a stipule, while on other stalks it is entirely absent. One stalk is distinctly jointed and bears two bolls in a double involucre, an example of fasciation. The right-hand figure shows an abortive fruiting branch ending in a single leaf with enlarged stipules, and a simple axillary branch bearing a normal boll. (Natural size.)

Plate III. Part of a Maragogipe coffee tree on the Sepacuite plantation, Alta Vera Paz, Guatemala, showing three upright branches bearing numerous horizontal lateral branches. The leaves of this variety are larger, heavier, and more inclined to be crumpled than those of the ordinary Arabian coffee. (Greatly reduced.)

Plate IV. The left-hand figure shows one internode of a very young upright and a complete internode of one of its lateral branches, projecting underneath the right-hand figure. The right-hand figure shows an older upright where pruning has forced the growth of two new upright branches, with short basal internodes, arising below the bases of the nearly horizontal lateral branches. (Natural size.)

Plate V. A diseased condition of the lateral branches of Arabian coffee in eastern Guatemala, where the branching of the laterals has been forced by persistent pruning. (Natural size.)

Plate VI. A young cacao tree on the Trece Aguas plantation, Alta Vera Paz, Guatemala, showing the normal method of producing branches in whorls. The whorled branches do not give rise to upright shoots, which develop from the side of the old uprights underneath the whorls. (Greatly reduced.)

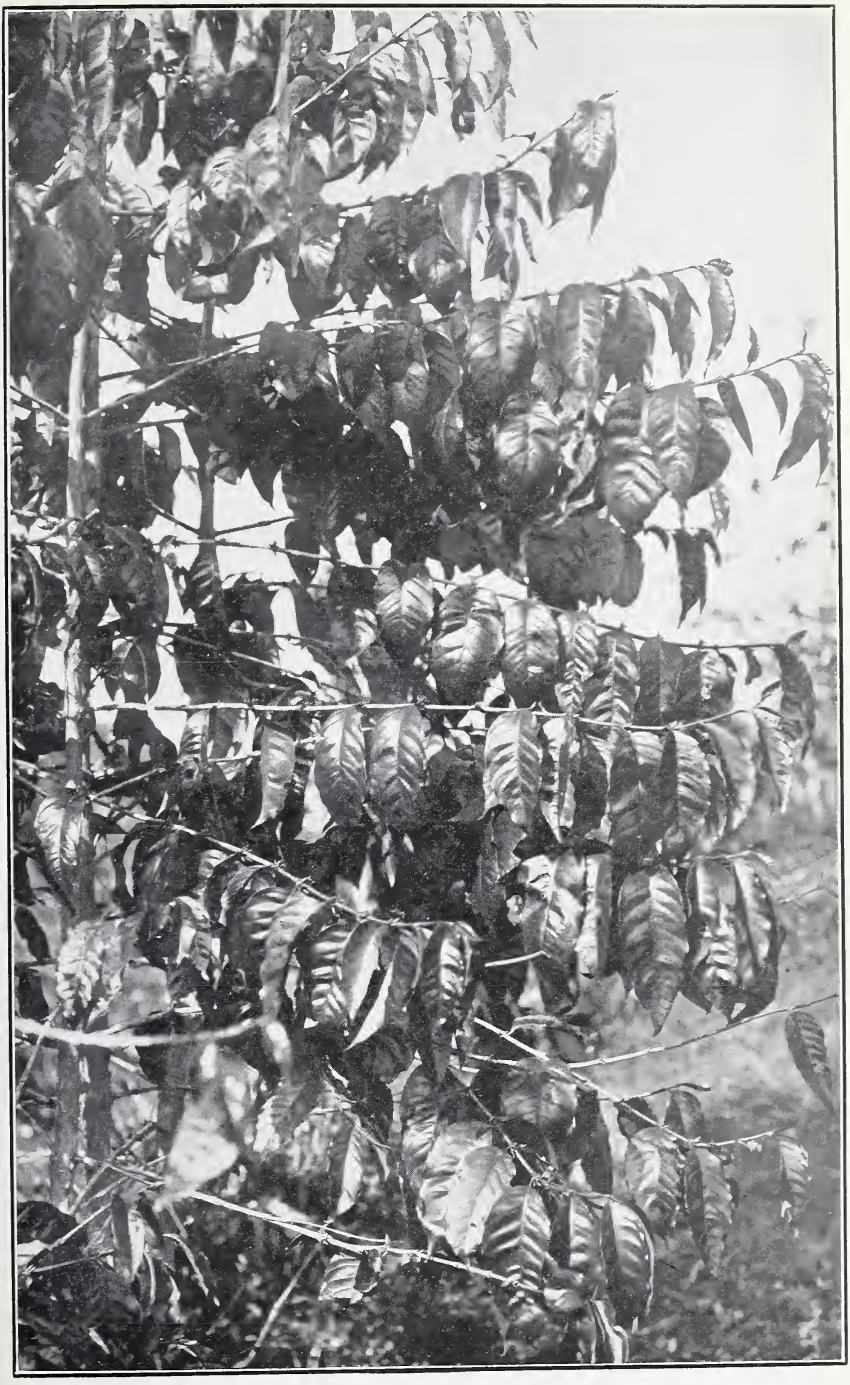
Plate VII. Fig. 1.—Petioles of leaves from uprights of cacao. The upright branches of the cacao produce leaves with the long petioles (left-hand side of the figure). The whorled branches produce leaves with short petioles (right-hand side of the figure). (Natural size.) Fig. 2.—Section through the rhizome of a banana plant showing that sword suckers are true branches of the rhizome, unlike the broad-leaved suckers that arise from buds near the surface of the ground. (Greatly reduced.)

ABNORMAL BRANCHES AND INVOLUCRES OF EGYPTIAN COTTON.

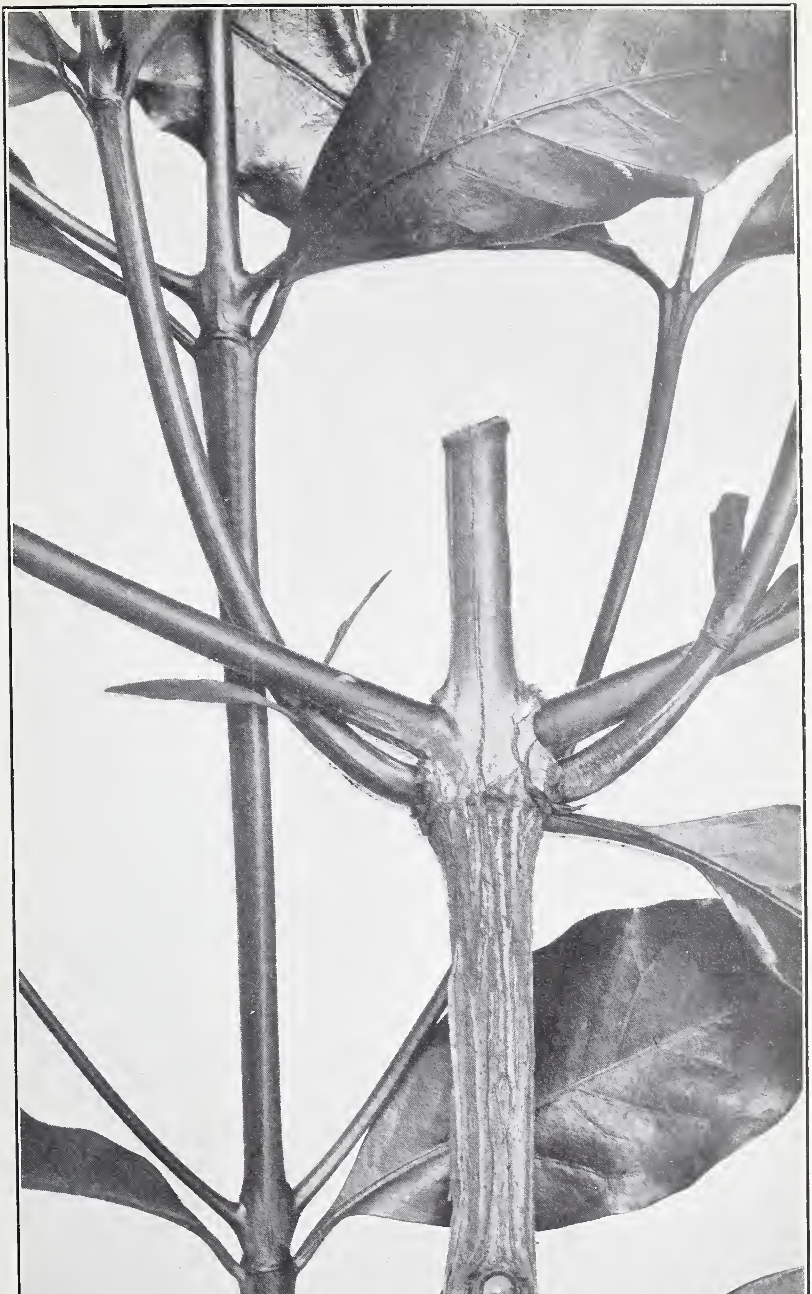
[Natural size.]

BOLLS PRODUCED ON SHORT AXILLARY BRANCHES OF EGYPTIAN COTTON.

[Natural size.]



COFFEE TREE, MARAGOGIPE VARIETY, SHOWING THREE UPRIGHT BRANCHES BEARING NUMEROUS LATERAL BRANCHES.



UPRIGHT AND LATERAL BRANCHES OF COFFEE.

[Natural size.]

ABNORMAL FORMATION OF LATERAL BRANCHES OF COFFEE.

A YOUNG CACAO TREE WITH TWO WHORLS OF BRANCHES.

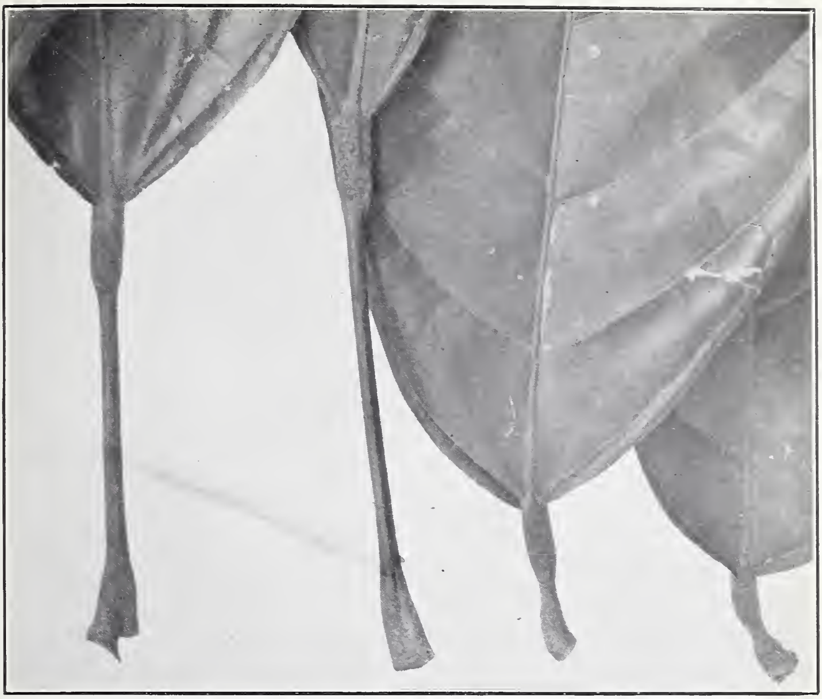


FIG. 1.—PETIOLES OF LEAVES FROM UPRIGHTS AND WHORL BRANCHES OF CACAO.

[Natural size.]

FIG. 2.—SECTION THROUGH BANANA RHIZOME, SHOWING ORIGIN OF SWORD SUCKERS.

INDEX.

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